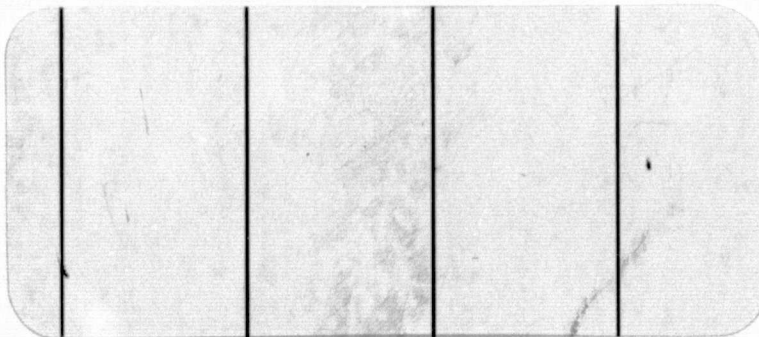


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ACCESSIBLE FOCAL PLANE TELESCOPE FOR SHUTTLE
Final Report (Perkin-Elmer Corp.) 138 p HC
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BOLLER & CHIVENS DIVISION

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DESIGN STUDY
of the
ACCESSIBLE FOCAL PLANE TELESCOPE
For Shuttle

6-17-76

FINAL REPORT
April 1976

CONTRACT NAS 9-14684
Mod. No. 2

Prepared for
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Lyndon B. Johnson Space Center
Houston, Texas



FORWARD

This final report on the design study of the Accessible Focal Plane Telescope (AFPT) was prepared by the Boller & Chivens Division of The Perkin-Elmer Corporation, South Pasadena, California for the NASA Johnson Space Center (JSC), under Contract No. NAS9-14684 Modification No. 2.

Boller & Chivens contributors were:

N. A. Page	Project Manager
F. G. O'Callaghan	Astronomical Systems Program Manager
R. H. Killen	Design Engineering Manager
C. C. Wheeler	Senior Staff Engineer
J. F. O'Rourke	Senior Staff Engineer
W. Willis	Engineer
J. Demaree	Concept Artist

The NASA Technical Monitor for this study was Dr. Karl G. Henize of JSC. He and Dr. T. R. Gull of Lockheed Electronics Company (under contract to JSC) have indirectly contributed to this study by establishing basic guidelines and by encouraging the adoption of a number of the technical concepts presented here.

Further questions concerning this report should be directed to:

Karl G. Henize, Code TE
Johnson Space Center
Houston, Texas 77058

INTRODUCTION

In July of 1974, in response to the Announcement of Opportunity for Spacelab UV-Optical Telescope (SUOT), a group of astronomers at Johnson Space Center headed by Dr. Karl G. Henize proposed an accessible-focal-plane telescope attached to the aft end of a Spacelab pressurized module. The rationale for such a configuration was to provide a facility for astronomy which met the fundamental concept of Shuttle sortie operation - a facility in which astronomers could operate low-cost manually-controlled instruments in a shirt-sleeve environment.

Although the proposal was successful and Dr. Henize eventually was appointed Team Leader of the SUOT Facility Definition Team, the Team and its sponsors concluded that several possible disadvantages (mainly the complex interface with the Spacelab module) had not been sufficiently studied and chose to focus their attention on a pallet-mounted configuration. In the meantime a study was initiated at Johnson Space Center to further investigate the feasibility of an accessible-focal-plane configuration. As a result, the Boller & Chivens Division of The Perkin-Elmer Corporation was contracted to perform a design study of an Accessible-Focal-Plane Telescope (AFPT) in sufficient detail to establish the feasibility of such a concept as well as its probable cost. The result of this design study is presented in this report.

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I. General Description of the Accessible Focal Plane Telescope

A. Physical Arrangement

The AFPT design resulting from this study may be divided into five general sections. The telescope tube, the telescope mounting, the airlock plus spacelab module aft plate, the instrument adapter, and the instrument package. These sections combine to make a system which allows access to the image plane with instrumentation that can be operated directly by a scientist in a shirt-sleeve environment inside a spacelab module. See Fig. 1.

B. Telescope Tube

The basic optical and mechanical design of the telescope is adapted from the Ball Brothers SUOT design.(ref. 1.2) Modifications consist of the removal of the instrument package, the addition of a third mirror to divert the last 1.5 meters of the optical path at a right angle into the spacelab module, and redesign of a portion of the telescope tube in order to interface it with the mount. The resulting configuration is shown in Fig. 2, 3 & 4.

C. Telescope Mount

The mounting interfaces with the telescope tube and the spacelab module and provides the required coarse pointing and guiding motions. It also provides support for the telescope tube during launch and re-entry. The mounting is joined directly to the spacelab module and does not require pallet support. In addition, the interface of the mount with the module has been designed so that support from the end cone and aft plate is not required.



FINDER TELESCOPE

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TELESCOPE TUBE

TELESCOPE MOUNT

AFT PLATE

SCIENTIFIC AIRLOCK

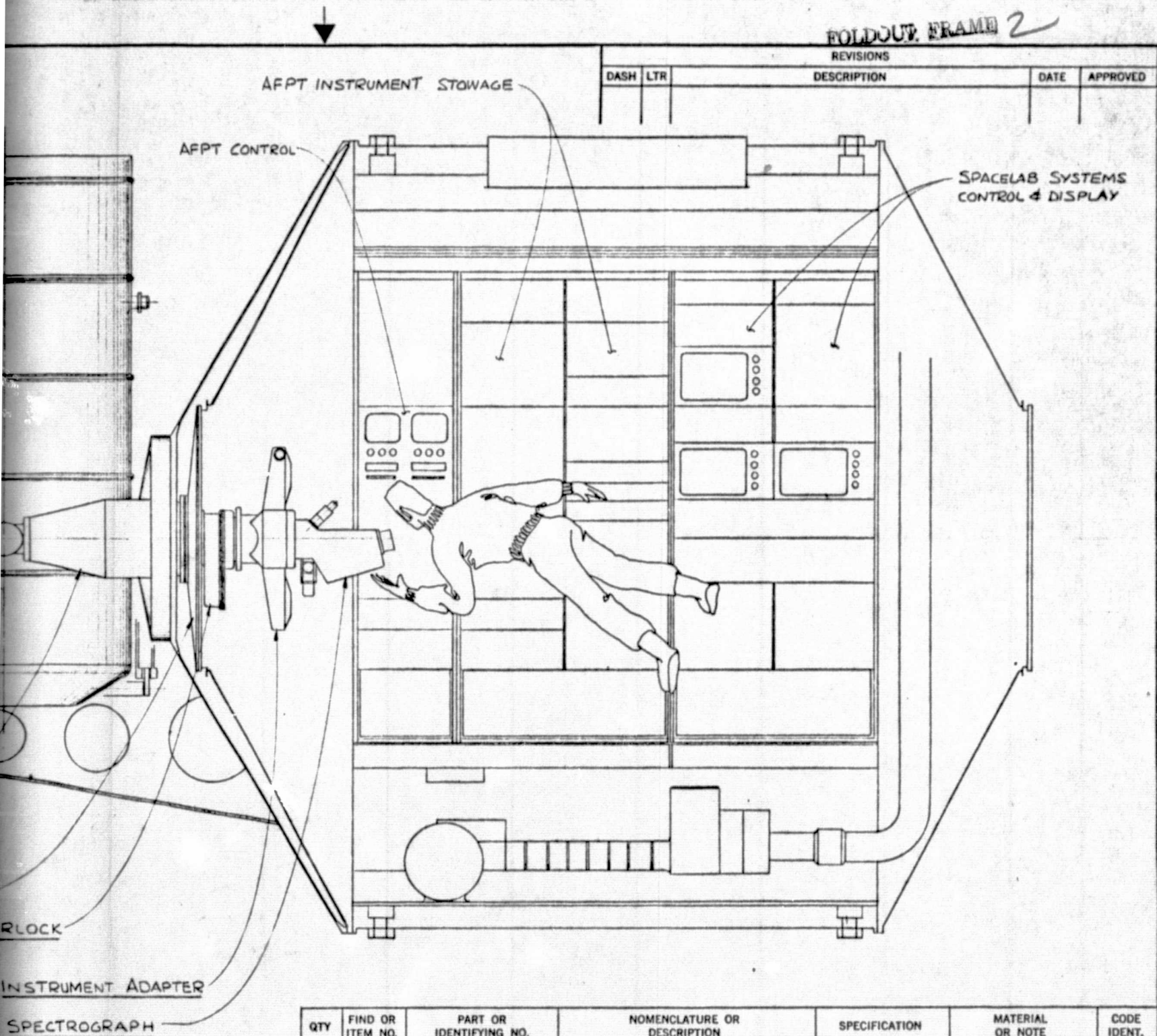
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INSTRUMENT ADAPTER

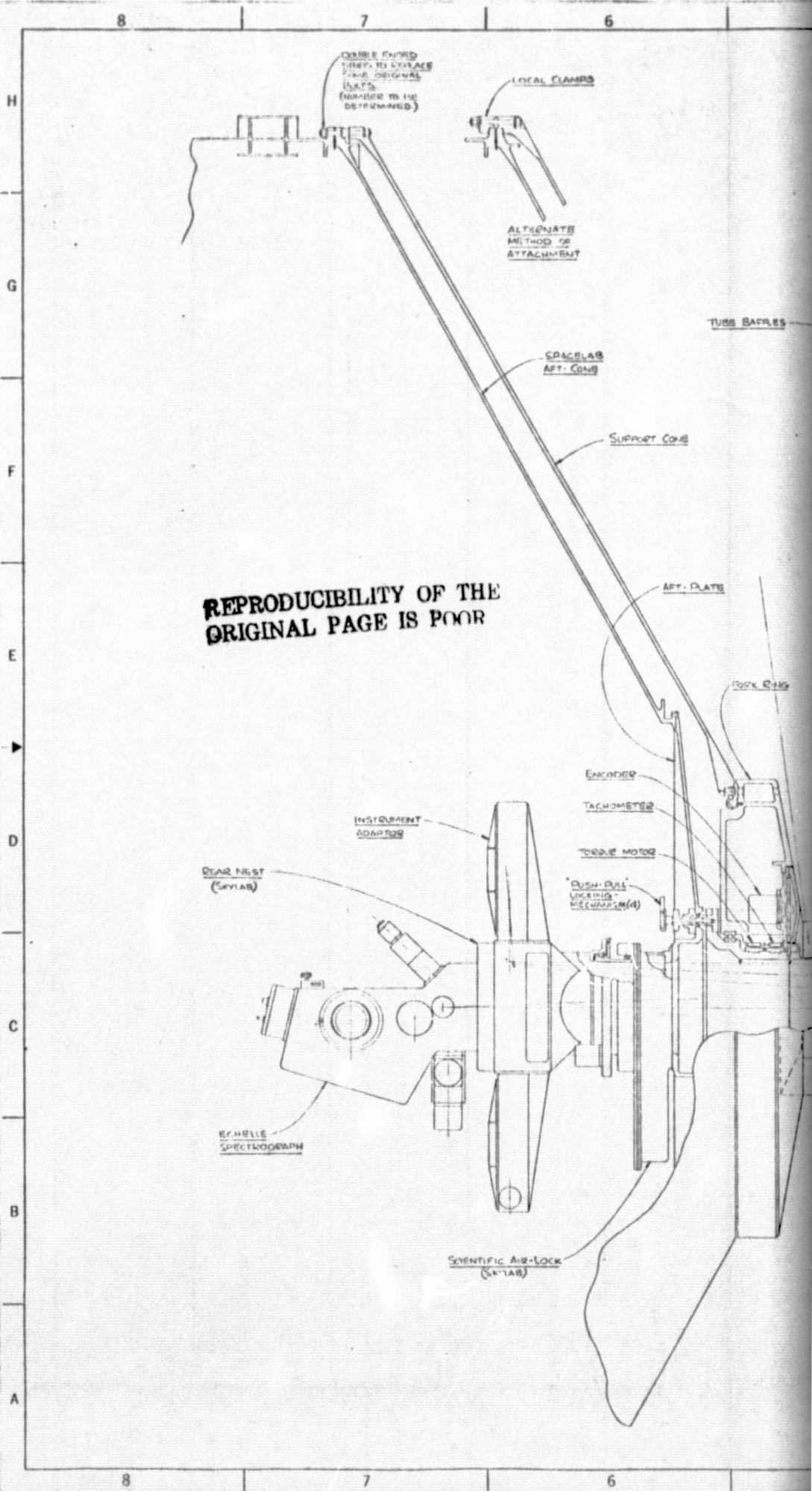
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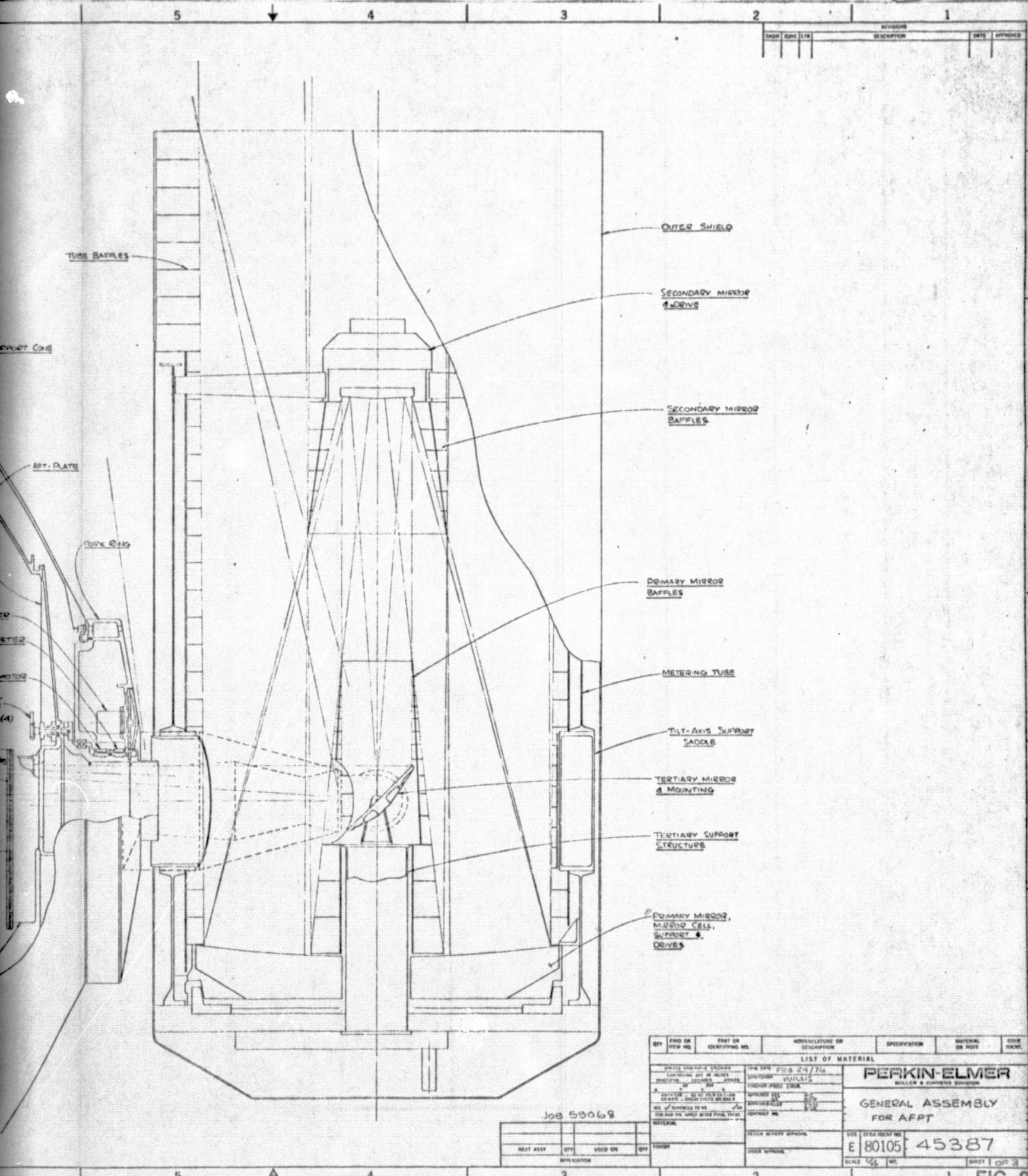
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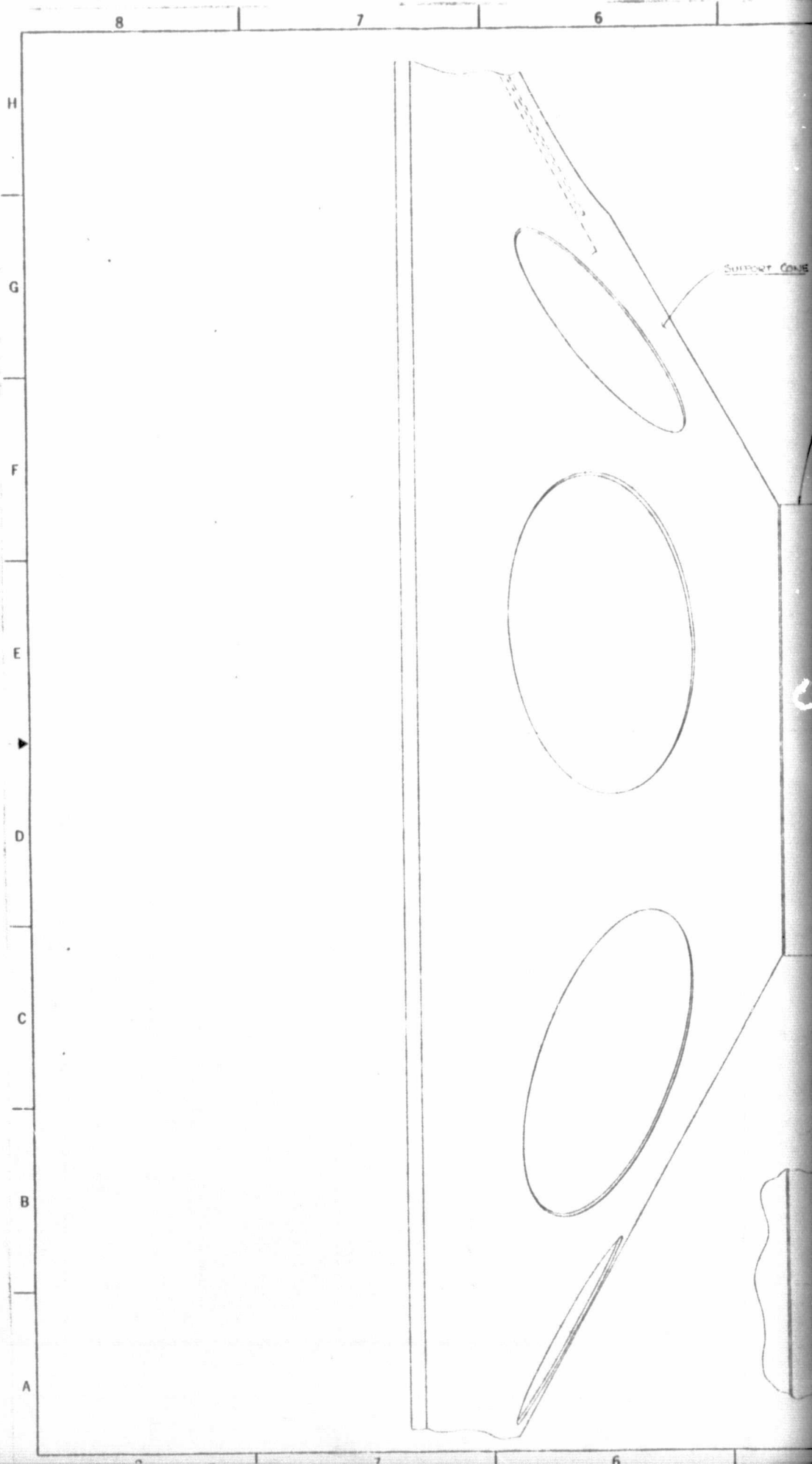
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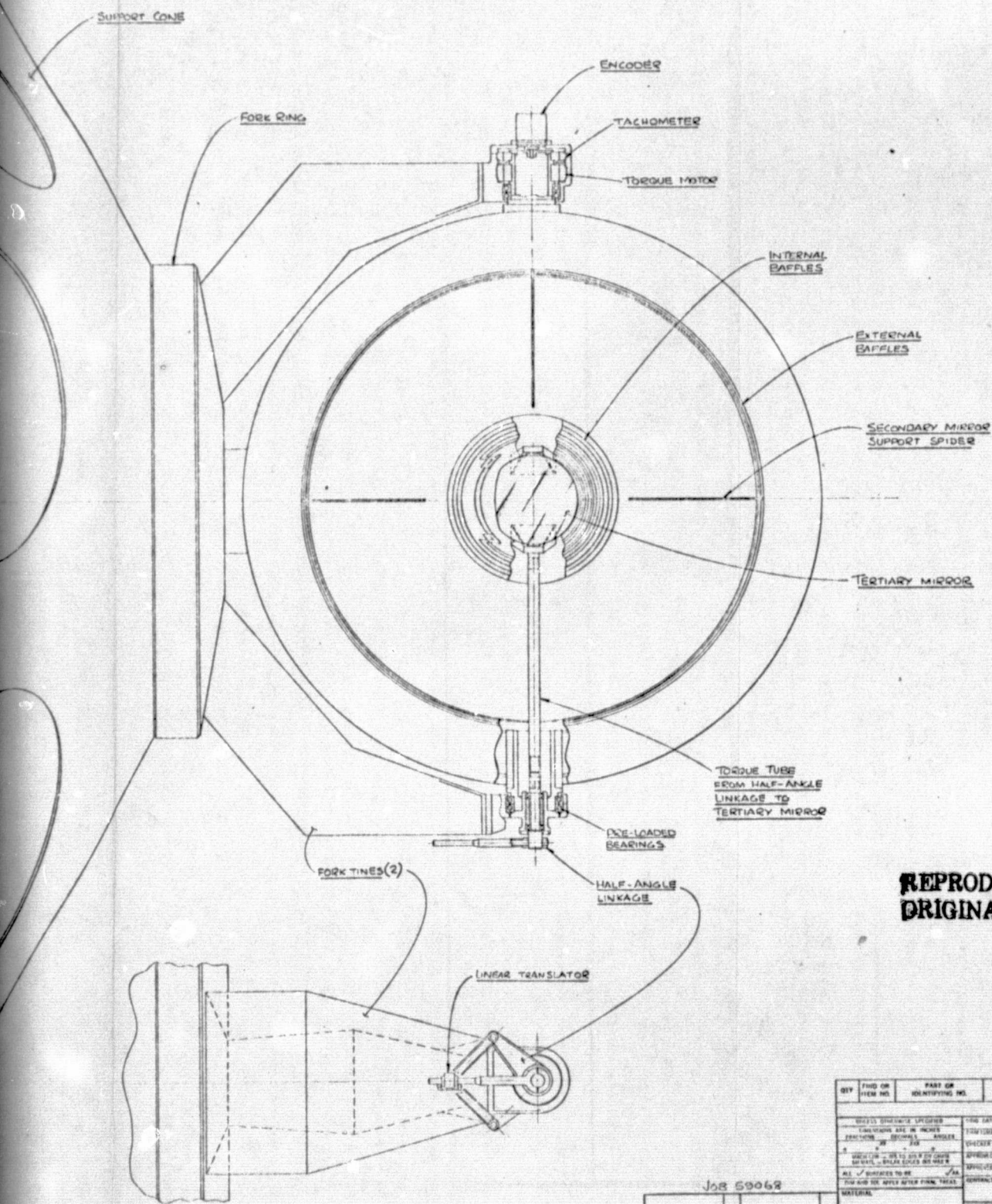


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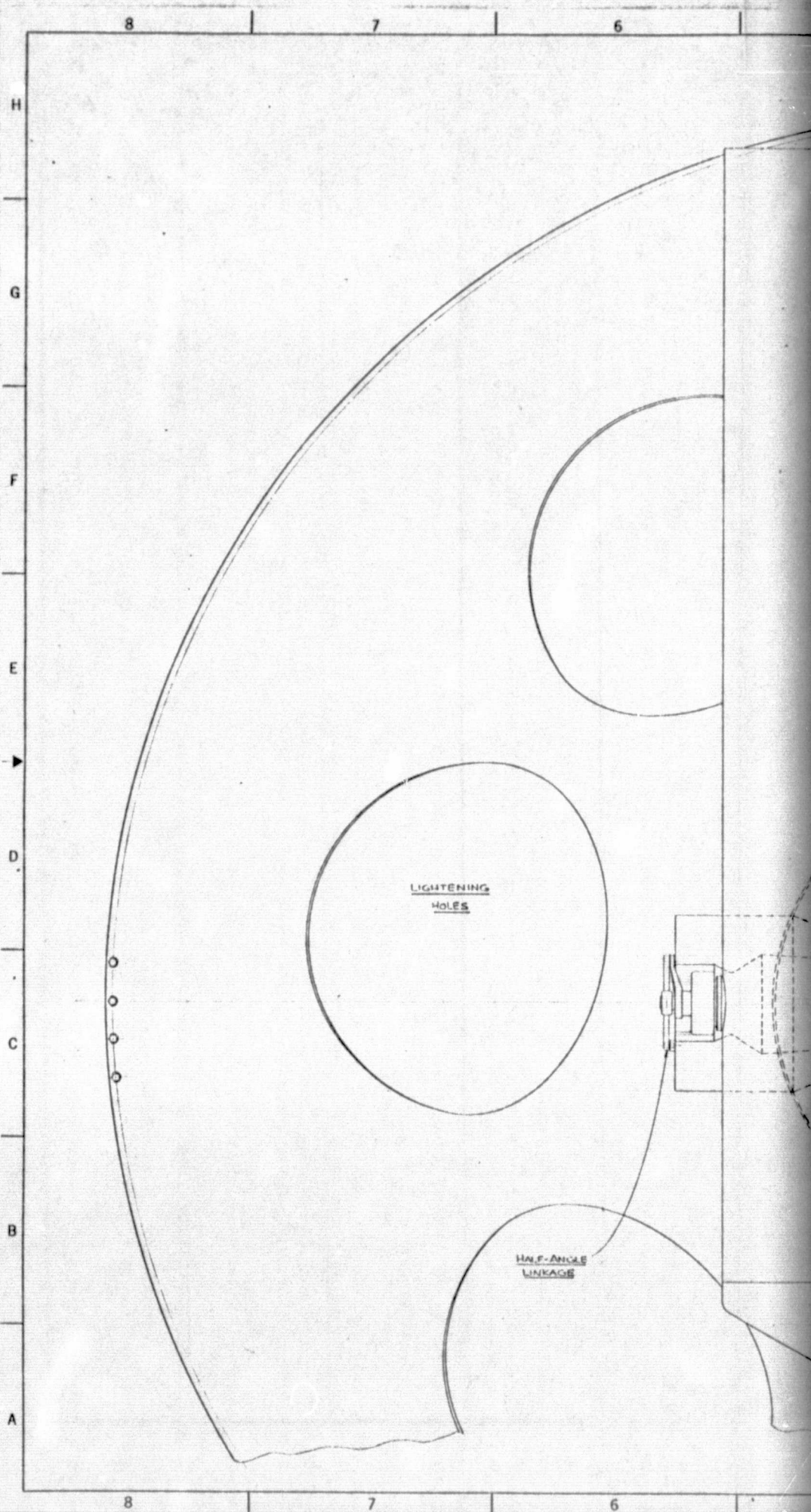
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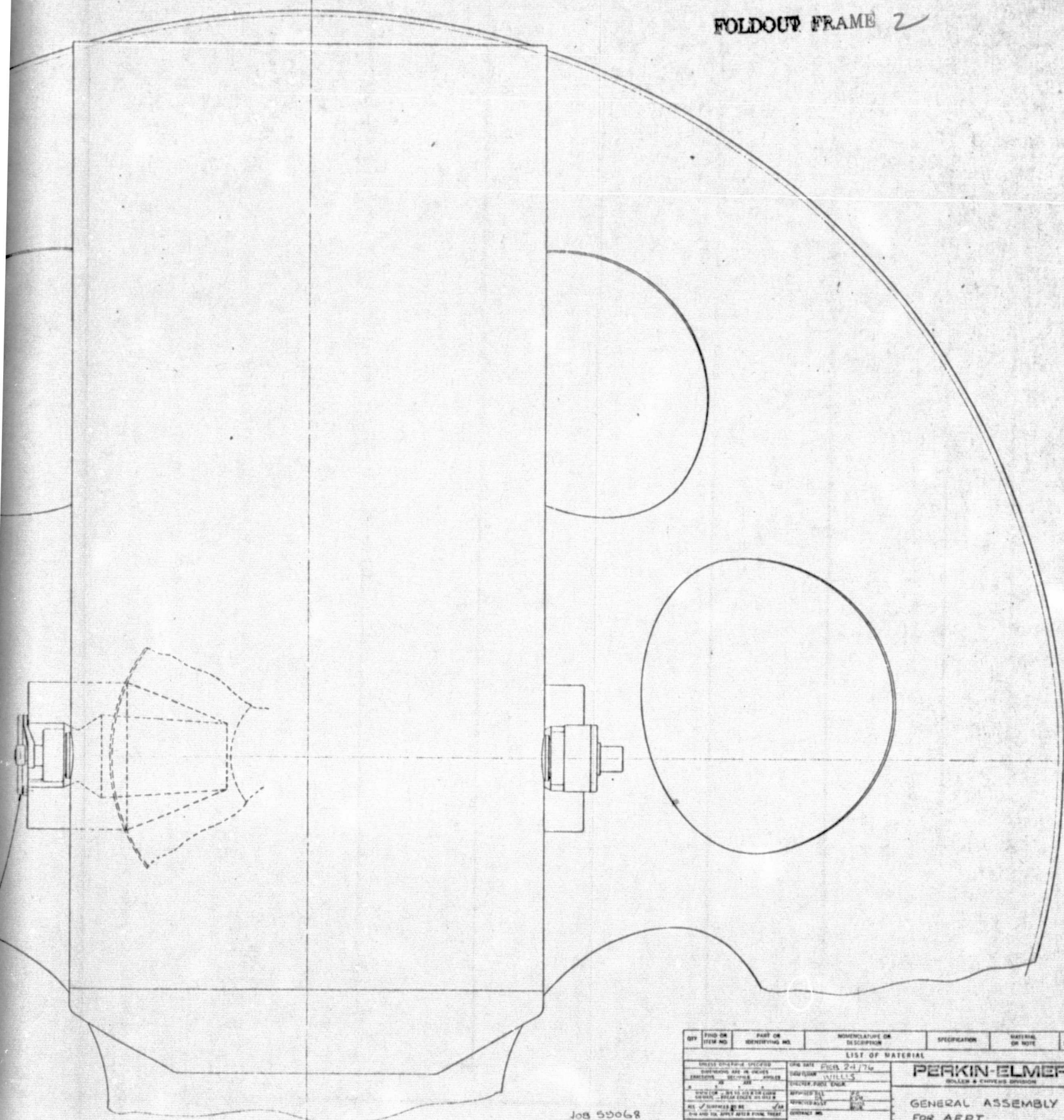
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FIG. 4

I. C. (cont'd)

No stressing of these sections occurs at any time during a shuttle flight due to the presence of the telescope mount. This is important during launch and re-entry.

D. Airlock and Aft Plate

The airlock is mounted to the interior side of the spacelab module aft plate and is the same design used on Skylab.

The aft plate is a modified version of the design. (ref. 5). It contains mechanisms for locking the telescope in its stowage support cradle for launch and re-entry as well as mechanisms for locking the telescope mounting rigidly, relative to the aft plate once orbit has been achieved.

E. Instrument Adapter

The instrument adapter, which attaches to the airlock, provides a universal mount for a wide variety of different instruments. Special provisions have been made to accommodate an electrographic direct imaging camera. The primary function of the instrument adapter is to de-rotate the image and to provide all the required error signals for tracking and stabilizing the image by means of a focal plane guiding system using focal plane detectors. This includes control of the secondary mirror for final image stabilization to $\pm .03$ arc sec. Secondary functions of the instrument adapter include a direct field viewing system for the purpose of target identification and alignment and providing a mounting surface for the Gascoigne corrector and field flattener. The instrument adapter has a quick-release retention mechanism for mounting scientific instruments. This mechanism is similar to the one on the airlock.

I. F. Instrument Package

For the purpose of this study, one instrument has been designed for use with the system. It is an echelle spectrograph which, with the interchanging of four sets of detectors, echelle and cross disperser gratings, can cover the spectral range between $1200\text{\AA}$ and 1.03 micrometers.

II

Modification to the SUOT Tube Design

A. Modifications to the Existing Design

The modifications necessary to adapt the SUOT tube to the AFPT mount are shown in Fig. 2. They consist primarily of the removal of the instrument package, the addition of a third mirror, and redesign of the graphite epoxy tube structure to accommodate a tilt axis support ring.

In the AFPT concept most instrumentation is located inside the spacelab module. However, it is highly desirable for two types of instruments, polarimeters and far UV (900-1100A) spectrographs to be located in the normal Cassegrain position in order to avoid the effects of the tertiary mirror (ref. 3). Such a concept may be incorporated into the AFPT concept since there is a 1.4 meter clearance at the rear of the telescope. Such an arrangement would require only minor modification of the present AFPT design to allow the tertiary mirror assembly to fold back out of the optical path, much like removal of Coude mirror systems on conventional ground-based telescopes.

B. Tertiary Mirror Mount

The mounting arrangement for the third mirror is shown in Fig. 2. As can be seen, it is supported by a structure extending through the hole in the primary mirror. The material chosen for this structure is the same graphite epoxy used for the telescope tube. This results in good thermal stability for the position of the mirror along the optical axis. The mirror mounting is also provided with a mechanism for tilting it from its nominal position (45° to the axis) by an amount equal to one half the angle the telescope optical axis is tilted from its nominal

II. B. (Cont'd)

position, (90° to the axis of the spacelab module). See Fig. 3. This mechanism is required in order to maintain the axis of the last 1.5 meters of the optical path exactly in alignment with the instrument adapter which houses the Gascoigne correctors and field flattener. It is driven mechanically by the movement of the main telescope tube relative to the mounting. It is located at the side of the tube in the vicinity of one of the fork arms. The mirror is driven by a torque tube which is optically in line with one of the secondary spider vanes and exactly on axis with the tilt axis bearings.

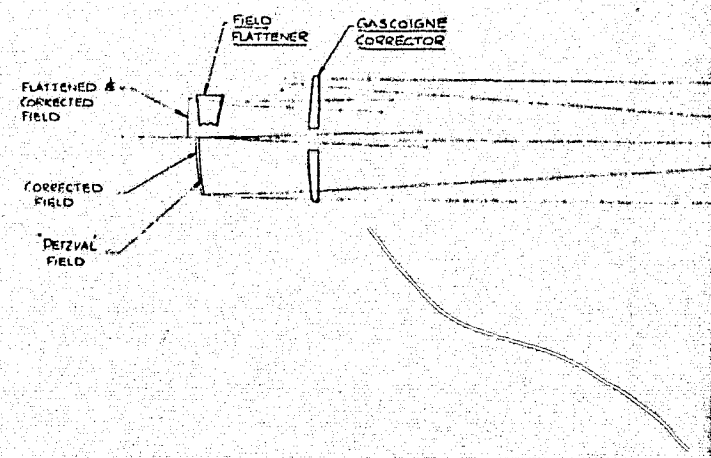
The half angle tilt mechanism (Fig. 3) has been used by Perkin-Elmer in similar applications. The mirror tilts $\pm 3.75^\circ$ on a flexure mount which provides a preload for the mechanism. The linear translator is a ball bushing mechanism. Experience has shown that the smoothness and precision of motion of this mechanism is in the ± 1.0 arc second range.

One area of concern relative to the implementation of the third mirror was its effect on the baffling of the telescope system. Since observations will be made in the day part of the orbit it is necessary to require that light from outside the field of view be reflected at least twice before reaching the image plane. The resulting configuration is shown in Fig. 5. The initial AFPT optical design couldn't be fully baffled because of the light striking the tertiary mirror as shown in Fig. 5, ray A. However, a working solution was achieved by extending the telescope tube 10cm and shortening the tertiary mirror.

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II. B. (Cont'd)

Some vignetting results, but only in the guiding portion of the field. No part of the data field suffers any vignetting. The worst case vignetting in the guiding field is about 14%.

C. Telescope Tube Modifications

The modifications necessary to connect the mounting fork to the telescope tube are shown in Fig. 2. The metering tube is divided into two sections with the addition of a structural support ring between the two sections. It is a hollow rectangle in cross-section and has been designed to be considerably stronger than the rest of the telescope tube. The material chosen for this structure is the same graphite epoxy used in the SUOT design. This results in the same thermal stability as in the original design.

D. Finder Telescope

A wide-field (3° diameter) finder telescope is necessary to facilitate the acquisition of fields. Although Orbiter can be oriented to within 0.1 degree using its startrackers, pointing misalignments between the Orbiter startrackers and the payload experiment mount can be as large as two degrees.

The optical system of the proposed finder telescope is a 100mm aperture, $f/1.75$ telescope which images a three-by-three degree field on view onto a 400-by-400 element charge coupled device (CCD). Such a system should be able to detect and track 10th magnitude stars accurate to two arc seconds. Such a finder telescope is being developed by a group headed by Mr. John McLauchlin at Jet Propulsion Laboratory (ref. 6).

III. Telescope Mounting

A. General Configuration

The general configuration of the telescope mounting is shown in Fig. 2. It is a fork type design with two duplex bearing sets supporting the telescope tube at the tilt axis and a single four point contact bearing supporting the mounting at the rotation axis. The tilt axis has a $\pm 7.5^\circ$ range of movement and the rotation axis has a $\pm 90^\circ$ range of movement. $\pm 70^\circ$ of the range is used for observing (no vignetting by the shuttle vehicle) with the remaining 10° being used to bring the telescope tube into its stowage position in the launch and re-entry support structure. Both axes are driven by torque motors with tachometers. The tilt axis motor is capable of producing a torque of 14 lb-ft which is quite adequate for handling the bearing friction which is expected to be on the order of 0.25 lb-ft. The rotation axis bearing, however, has quite a bit more friction; 44 lb-ft. In both cases, the torque available above that required to overcome the bearing friction is required to provide the accelerations necessary to follow angular accelerations of the shuttle vehicle caused by thruster firings. The bearing friction, particularly in the rotation axis, may vary as much as 20%, however, this is not a problem since it will occur on a very low frequency basis and can easily be handled by the servo drive system. A summary of the driving torques and resulting power requirements is tabulated in Appendix A. Each axis also has a 17 bit absolute encoder for pointing to ± 0.2 arc minute. More precision than this is not required since the telescope need only be pointed accurately enough to acquire the target in the 3° field of the bore sight finder telescope mounted on the main telescope tube.

III. A. (Cont'd)

The tilt axis encoder is mounted directly to the shaft while the rotation encoder is mounted off axis and coupled to its shaft by a 2:1 gear train.

B. Interface with Spacelab Module

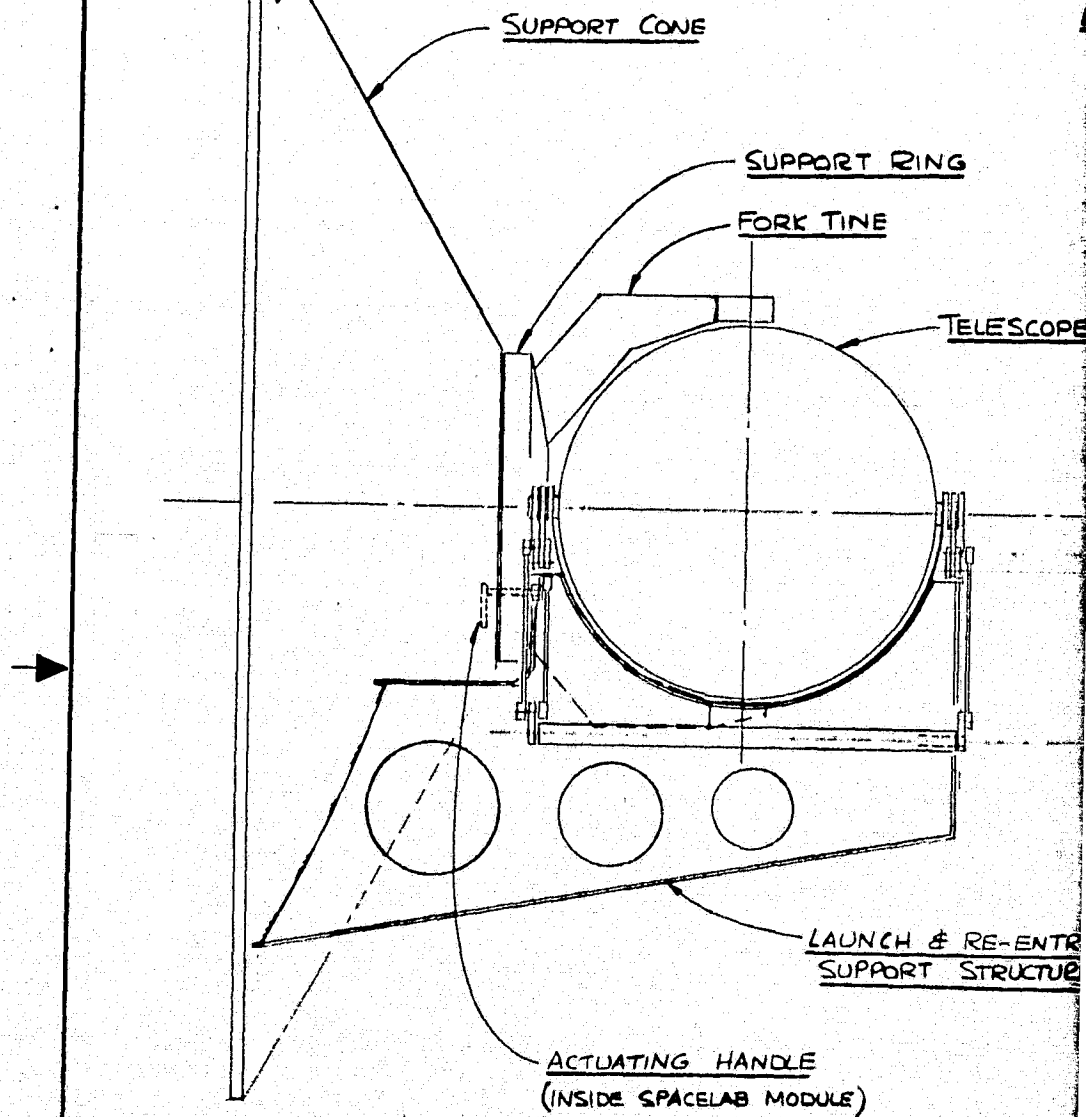
It is a basic guide line of the study to minimize the mechanical interface between the AFPT mount and the spacelab module. This has been achieved by supporting the AFPT on a cone which covers the aft cone structure of the spacelab module without touching it. The base of the support cone attaches directly to the structurally sound bolt ring at the aft end of the cylindrical section of the module. This ring also provides the structural tie between the module and the shuttle. During launch and re-entry the AFPT facility is attached only to the bolt ring. During orbital operations (when the mount is subjected to very little stress) it is necessary to directly connect the airlock in the module aft plate to the telescope mount in order to preserve precise optical alignment and focus during observation. Such a connection does not constitute a modification to the existing module aft plate since it is proposed that the existing aft plate be replaced by a special one tailored to accommodate the airlock and the above-mentioned connectors. Thus, the only interface with the module required by these modifications will be a replacement of the aft plate plus the attachment of this base of the support cone to the spacelabs bolt ring.

C. Launch and Re-entry Support Structure

The mounting is also provided with a launch and re-entry support structure for the telescope tube, Fig. 6. It is mounted to the support cone which interfaces the mounting to the spacelab module. The axis of the telescope is parallel to the Y axis of the shuttle vehicle during launch and re-entry. Locking of the telescope in this position is accomplished by driving it to the zero position and actuating a manual mechanical linkage from inside the spacelab module. The linkage operates through a rotary vacuum feed-through in the aft plate.

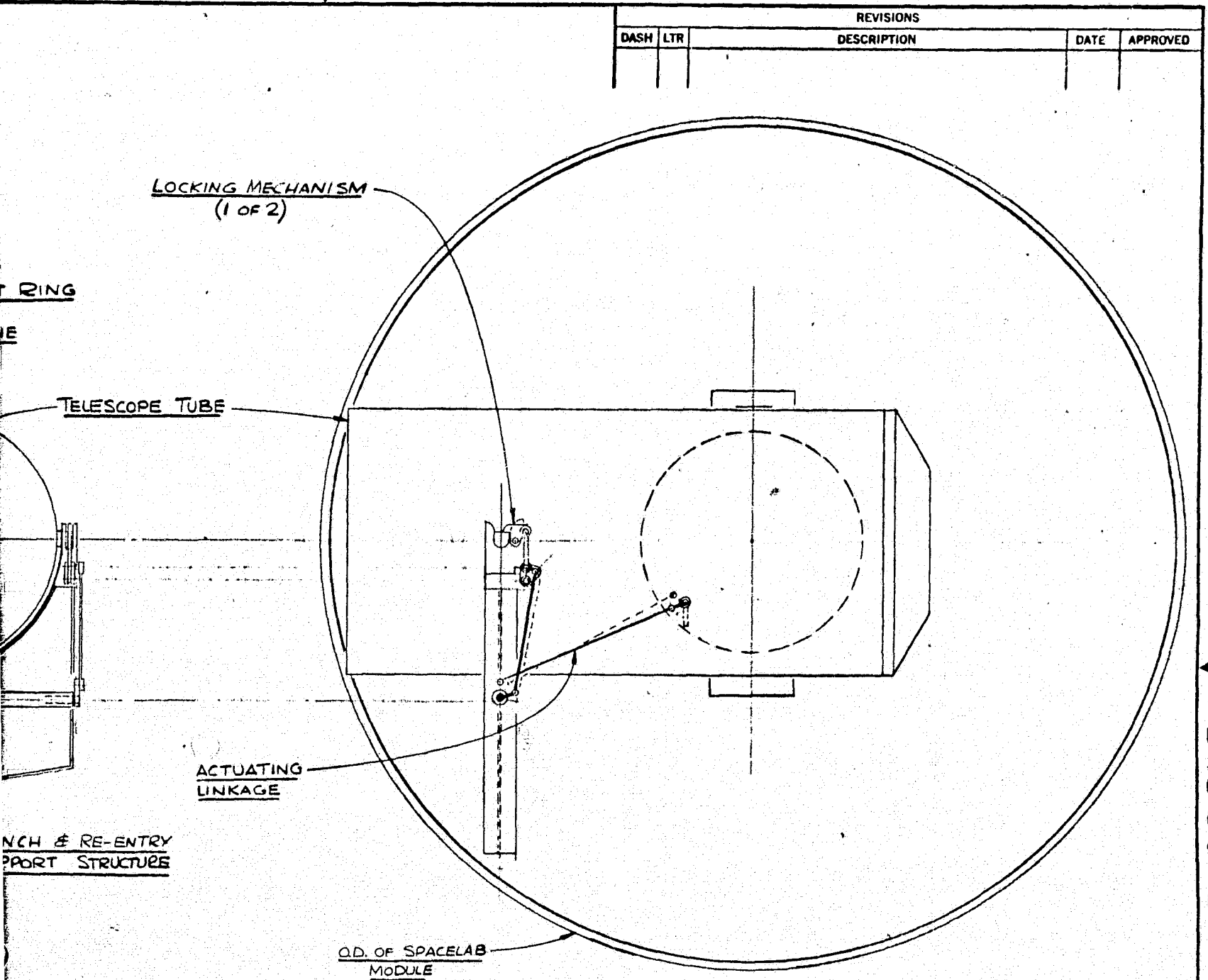
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APPLICATION			SCALE 1/16	WT.	SHEET 1 OF 1	

JOB 59068

FIG.6

III. D. Construction

Construction of the mounting is largely of welded aluminum plate (2219-651). Some of the smaller sections are machined from solid stock. One concern with the aluminum structure is that parts of it retain steel bearings. Differences in the relative coefficient of expansion must be accounted for in the mounting design. As a result, it was decided to control the temperature of these sections by thermal heating and blanketing. The design calls for thermal blanketing of some parts of the dynamic portion of the mounting in the vicinity of the bearings and complete blanketing of the support structure which interfaces the mounting with the spacelab module. The weight of the mounting and telescope tube is 995 kg (2194 lbs). The mounting by itself weighs 542 kg (1194 lbs).

E. Structural Considerations

The structural analysis of the telescope mount is detailed in Appendix A. The stiffness of the mounting is high resulting in natural frequencies of 50.5 Hz in the X-axis, 33.6 Hz in the Y-axis, and 41.7 Hz in the Z-axis. As a result of the telescope mount being relatively stiff, most of the stress levels in the structure itself are quite low, even considering the worst case conditions which occur during "solid rocket cut-off" for the X-axis, and "launch release" for the Y-axis and the Z-axis. Stressing of the spacelab module due to the presence of the telescope mounting is also quite low. It is about one-eighth the stress caused by the internal pressurization of the module.

III. F. Performance

There does not appear to be any problem with the capability of the mounting to track under normal conditions to ± 2 arc seconds. Calculations detailing the effects of crew motion and thruster firings on the tracking precision are tabulated in Appendix B. Indications are that both the crew motions and small thruster firings have about the same effect on the telescope pointing errors(ref. 4). The magnitude of the telescope pointing and final image stabilization errors are, of course, dependent upon the characteristics of the servo system employed.

It is recommended that a non-linear digital servo system controlled by a computer (mini or microprocessor) be used to control both the rate at which the main telescope mount is driven and the tilt angle of the secondary mirror. In such a servo system, the computer samples the angular error of the image from its nominal guiding position (as indicated by the focal plane tracker) at intervals equal to T , where T equals the time constant of the trackers, and makes corrections by tilting the secondary mirror. The computer also makes corrections in the speed at which the main telescope mount is being driven according to the following algorithm:

$$\Delta \omega_m = \frac{1}{T} (K \theta_T - \theta_{T-1})$$

Where $\Delta \omega_m$ equals an incremental drive speed correction (arc sec/sec), T (as mentioned above) equals the time constant of the focal plane tracker (sec.), θ_T equals two times the angle the secondary is presently tilted from its nominal position (arc sec), θ_{T-1} is the same value for the last sample, and K is a constant which determines the effective damping characteristic of the system. The system is critically damped when $K=2.0$, over

III. F. Performance - (Cont'd)

damped when K is less than 2.0 and under damped when K is greater than 2.0.

The excursion of the image from its nominal position in the focal plane due to vehicle disturbances is very dependent on the time constant of the CCD focal plane tracker. With a time constant of 0.1 sec, crew motions can cause the image to be outside the desired $\pm .03$ arc sec for short periods of time. However, if the tracker can be operated with a 0.05 sec time constant, the image could be kept within the $\pm .03$ arc sec at all times. Minimum errors, of course, will result when the system is critically or slightly under damped.

IV. Airlock and Aft Plate

- A. As a cost saving measure it was directed that the design of the airlock be the same as that of the existing Scientific Air Lock (SAL) of Skylab. It is a fortuitous coincidence that its 20cm x 20cm aperture is just adequate to transmit the converging optical beam.

To accommodate the SAL as well as the mechanisms for locking the aft plate to the telescope mount and for locking the telescope into its launch cradle the aft plate has been redesigned.

The mechanism for locking the aft plate and mounting together is shown in Fig. 2. It is a push-pull coaxial screw arrangement which is actuated with three rotary knobs from inside the space-lab module. One knob extends a part which engages a conical socket on the telescope mount. A second knob locks the extended part and conical socket together. The third knob locks the extension thread eliminating all freedom of movement between the aft plate and telescope mount. The mechanism has been designed to be vacuum tight. Triple Viton O-ring seals are used on all rotating parts of these mechanisms. It should be noted that the aft plate is indirectly locked to a dynamic part of the mounting via a four point contact bearing. All freedom of motion of the end plate relative to the dynamic portion of the telescope mount is restricted except rotation. It would have been somewhat more desirable to lock the aft plate directly to a rigid static part of the mounting. However, no space was available for implementation of such a structure. This is the result of the fairly limited distance (1.5 meters) between the telescope axis at the tertiary mirror and the image plane. The back focus of the telescope could have been changed to increase this distance. However, it was a basic guideline that the existing SUOT optical design be used for the AFPT.

V. Instrument Adapter

A. General Configuration

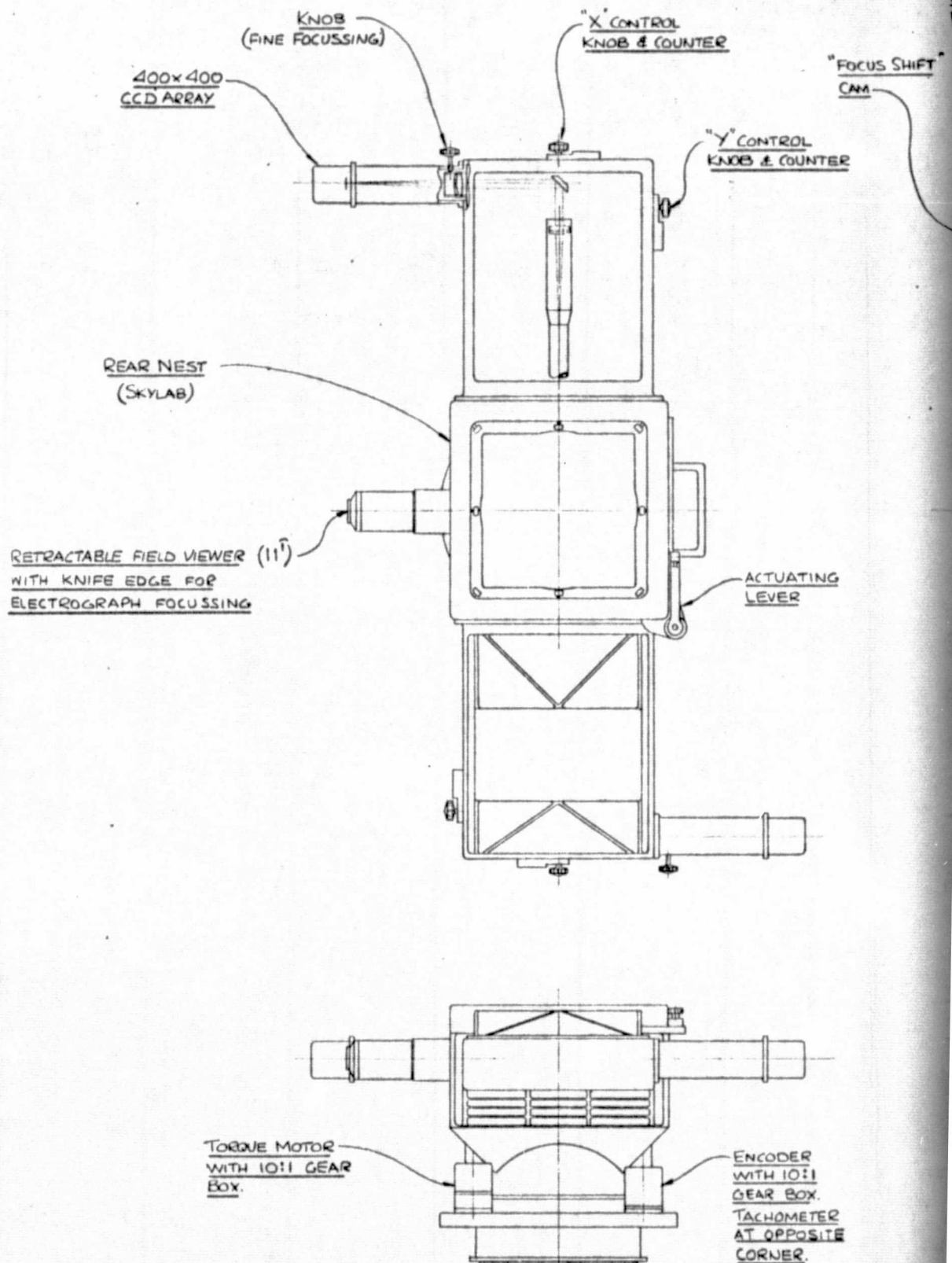
The configuration of the instrument adapter is shown in Fig. 7. Mechanically, the instrument adapter is divided into two main sections, which are connected by a rotating vacuum joint. The front section connects to the SAL by means of a square flange. The rear section contains a direct field viewing system, sensors for the image motion compensation (IMC) system, mountings for two optical correctors, and a retention mechanism to which scientific instruments may be attached.

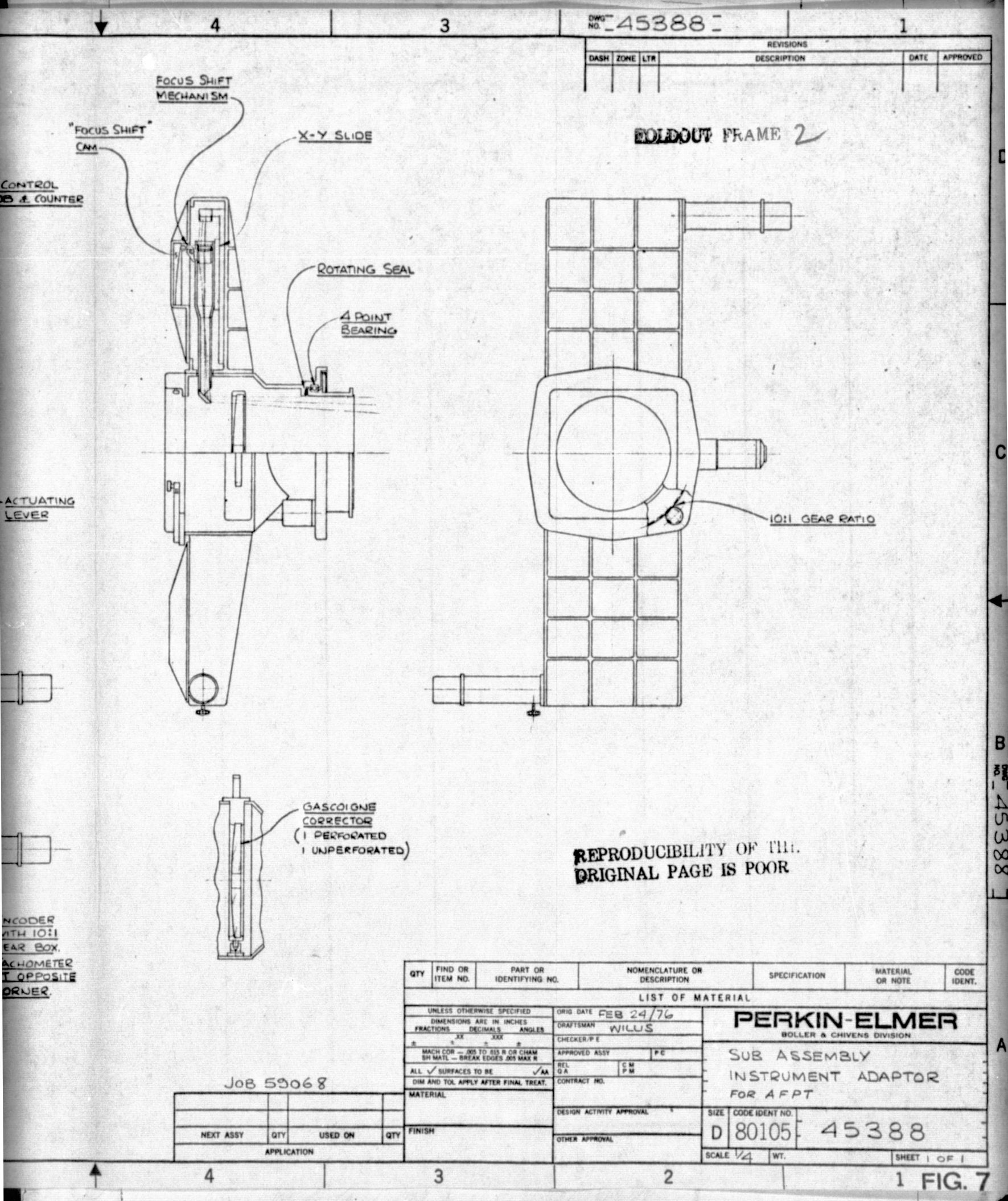
B. Rotating Joint

The rotating joint is driven by two torque motors with tachometers. Each torque motor is mounted off axis and drives the joint through a 10:1 gear train. One torque motor drives the joint, while the other controls the backlash in the gear train by applying a reverse torque. The rotating joint is also provided with a 10 bit encoder which is also mounted off axis and driven by means of two gear meshes of 10:1 and 1:10. A summary of the torque and electrical power requirements is outlined in Appendix A. The maximum speed at which this joint needs to be driven is $4.6^\circ/\text{min}$ which is the orbital rate plus the free drift rate of the vehicle. Slewing is accomplished manually. The limit of movement is $\pm 360^\circ$.

The rotating joint is provided with a 10 bit encoder. The purpose of the encoder is to indicate the relative rotation orientation of the rear section of the instrument adapter to the telescope mount.

FOLDOUT FRAME





V. Instrument Adapter (Cont'd)

B. Rotating Joint (Cont'd)

This information is required in order to translate the direction of image motion sensed by the IMC detectors into telescope tilt and rotation corrections. The output of this encoder must be fed both into the telescope control computer, as well as into the servo system controlling the secondary mirror.

Several vacuum seals were considered for the rotating joint. A summary of the drive and power requirements is detailed in Appendix A. The drive and power requirements tabulated are based on using lubricated double Viton O ring seals. There is no doubt that the Viton O ring seals can be qualified, but they have an undesirably high friction-about 10.8 lb-ft each. A considerable reduction in the drag could be realized if either Bal-seals or Omniseals could be used. Their drag is only 1.25 lb-ft for the Bal-seal and 1.6 lb-ft for the Omniseal. However, it remains to be seen whether such seals can be space qualified.

C. Direct Field Viewing System

Also contained in the rear section is a direct field viewing system. It is used for field identification and fine alignment of the image. Viewing is accomplished by means of a 75mm focal length eyepiece and a diagonal mirror which can be moved in or out of the optical path. The field diameter is 11.0 arc minutes. The design can accommodate interchangeable eye pieces so that very high power viewing of images is also possible. For example, a 15mm focal length eye piece may be

V. Instrument Adapter (Cont'd)

C. Direct Field Viewing System (Cont'd)

used to give a power of 1000. Such an arrangement would allow the eye to achieve an angular resolution of about 0.1 arc sec. Such a capability would be useful both scientifically (e.g. for visual observations of very close double stars), and technically (e.g. for monitoring image quality and mirror alignment).

D. Image Motion Compensation (IMC) System

The IMC System consists of a pair of focal plane detectors, and a servo system which corrects image motion by tilting the secondary mirror. The servo system and the drive for the secondary mirror are beyond the scope of this study and it is assumed that they are identical to those which were proposed by BBRC for SUOT. However, since the focal plane sensing system is an integral part of the AFPT instrument adapter, their nature and their positioning systems are included in this study.

The sensors for the IMC system consists of two independent optical systems and detectors, each of which can access any part of a semi-field (See Fig. 8). Together, the whole field can be covered. The detector in each system is a 400 x 400 CCD array with elements on 23 μ m centers. The device is currently being developed by JPL and is approximately 9mm square. It presently can detect image movements in the 2 μ m range. Its spectral response extends from 4000 $\text{\AA}$ to 9000 $\text{\AA}$. In the focal

FOLDOUT FRAME

OPTICAL
AXIS

0.4° (1/2 FIELD)

0.8° (14 MRAD)
FIELD

DISTANCE VARIES
DUE TO FIELD
CURVATURE

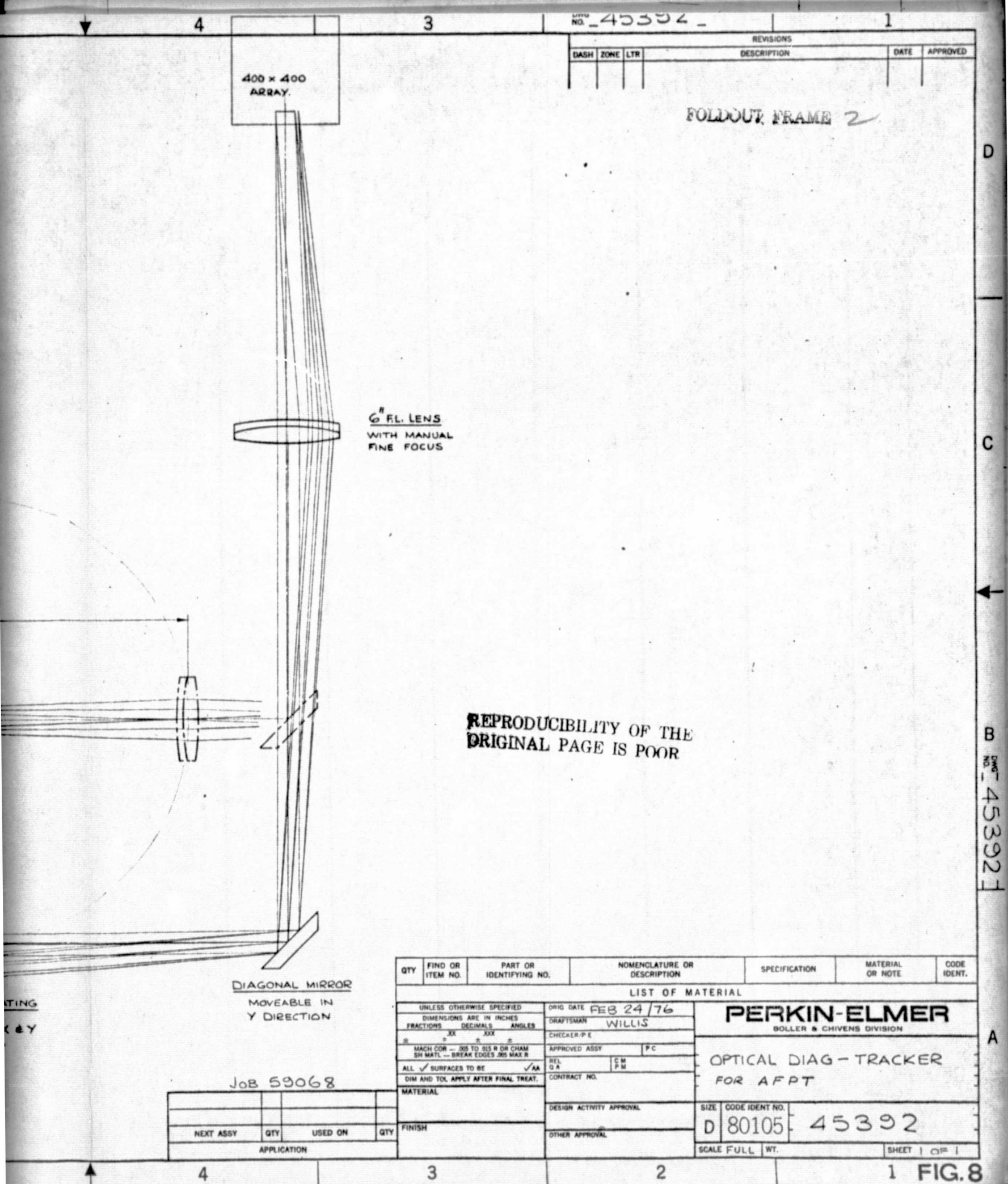
11.62°

PROBE MIRROR
MOVEABLE IN X & Y
DIRECTIONS

DIAGONAL

.325mm
DEPTH OF
FOCUS @
400nm = .36mm
(RAYLEIGH LIMIT)

6" FL. COLLIMATING
LENS.
MOVEABLE IN X & Y
DIRECTIONS



V. Instrument Adapter (cont'd)

D. Image Motion Compensation (IMC) System (cont'd)

plane tracking system the CCD is capable of guiding with ± 0.03 arc seconds tracking error on stars as faint as 13th magnitude. The mounting for the CCD detector is stationary which allows thermoelectric cooling by a heat exchanger that is located on the outside of the instrument adapter housing. No plumbing for cooling fluids is needed since the exchanger is simply a metal heat sink device with fins.

The optical system for each guider probe consists of a pick-off mirror, a collimator, a diagonal mirror, and a focusing lens. Movement of the pick-off mirror, collimator, and diagonal mirror, by means of mechanical controls on the outside of the housing, allows each CCD detector to optically view any part of a 100mm x 200mm area in the image plane. The pick-off mirror, collimator, and diagonal mirror all move as a unit. The distance between the collimator and pick-off mirror is fixed. The distance between the collimator and diagonal mirror varies depending upon where the pick-off mirror is located in the image plane. Positioning of the pick-off mirror is based on an X-Y coordinate system with independent controls for X and Y. The position is indicated to 1.0mm by digital readouts.

Optically, the CCD is located behind the Gascoigne corrector but in front of the field flattener. As a result of this and the fact that the CCD is statically mounted, the image plane is slightly tilted when working with parts of the image plane other than the center. At the very edge this amounts to 11.0 arc minutes. This is not a problem, however, since the CCD works best on slightly defocused images which extend over at least a 2 x 2 element subarray. Since the telescope will

V. Instrument Adapter (cont'd)

D. Image Motion Compensation (cont'd)

produce near diffraction-limited image diameters of about $20\mu\text{m}$, defocusing is required to produce images with approximately $40\mu\text{m}$ diameters. The defocusing effect of the tilted image plane is small compared to images this size. Current tests at JPL indicate that the CCD is capable of detecting displacements of such images as small as $2\mu\text{m}$ (i.e. 0.03 arc seconds).

Diameter of the stellar image on the CCD is adjustable by manual controls on the outside of the instrument adapter housing which vary the distance between the focusing lens and the CCD. Whatever position the focus is adjusted to is automatically maintained as the effective viewing position of the guider in the image plane is varied. This is necessary because the pick-off mirrors are before the field flattener in the optical path of the telescope.

Alignment of each of the CCD arrays is such that it is parallel to the X-Y coordinate system for its effective optical location in the image plane as well as the slit of the spectrograph when it is in use with the system. The reason for this is that the null position for guiding on the CCD is shifted digitally to accomplish widening.

Ordinary guiding is accomplished by using one of the CCD trackers to control movement of the main telescope mount motions (tilt and rotation) and the secondary mirror, while the second is used to control the rotation of the instrument adapter. Either tracker can serve either function. In addition, either tracker by itself can serve both functions to a limited extent.

V. Instrument Adapter (cont'd)

E. Optical System Correctors

A Gascoigne corrector and a field flattener are mounted in the instrument adapter. The Gascoigne corrector is used in two versions which can be interchanged. One has a hole in it for use with the spectrograph. In this mode the corrector provides the image quality required by the IMC detectors, yet passes a central beam to the spectrograph which is free of absorption from the corrector material. The field flattener is also removable for on-axis spectroscopy. Since spectroscopy uses only the center of the field, correction for astigmatism and field curvature is not needed.

F. Retention Mechanism

The retention mechanism for connecting an instrument to the adapter is placed slightly ahead of the field flattener so that an electrographic direct imaging camera can be used with the adapter. This provides clearance for the magnet which extends out in front of this type of device. The retention mechanism is identical to the one on the SAL and allows mating and demating in a matter of seconds once the SAL is closed.

VI. Echelle Spectrograph

A. Configuration

The spectrograph is a versatile instrument, providing high spectral resolution over a wide spectral range. The design is based on spectrographs used at ground based observatories, but modified to take advantage of the unique benefits of space such as the extended ultraviolet response and the diffraction limited telescope images. A single slit is provided for observations of stellar objects, and multiple slits, covering a 5mm (75 arc second) square format, for study of extended, emission line objects.

Like virtually all astronomical spectrographs, this echelle spectrograph has a data channel consisting of a slit, collimator, dispersing elements, a camera, a detector, and auxiliary systems including the comparison light system, a viewing system and order blocking filters.

In order to operate efficiently over the entire spectral range from 1200Å to 10300Å, this range has been divided into four spectral regions. For each region, a specific echelle grating, cross dispersing grating, blocking filter, comparison source and detector are used. Table 1 lists these spectral regions and the required units.

Figure 9 is an optical diagram of the spectrograph and Fig. 10 is an outline drawing of the exterior configuration. The design has interchangeable slit assemblies consisting of several

TABLE 1

ECHELLE SPECTROGRAPH CHARACTERISTICS

1. Spectral resolution ($\lambda/\Delta\lambda$); 1200/ (detector linear resolution (mm))
2. Dispersion ($\text{\AA}/\text{mm}$); λ_c ($\text{\AA}$)/1200
3. Length of any order (mm); 1200/spectral order number
4. Format, 25mm square
5. Separation of orders; 1 to 3.1 mm
6. Number of spectral regions; 4
7. Exposures required to cover any one spectral region; 3
8. Blaze angles

a. Echelle, 63.435° (R-2)

b. Cross disperser, 11°

λ_c

9. Spectral data

Wave Length at Center of Order

Order	Length mm	Separation mm	Region 1 $\text{\AA}$	Region 2 $\text{\AA}$	Region 3 $\text{\AA}$	Region 4 $\text{\AA}$
48	25	3.1	2100	3570	6060	1.03_μ
50	24	2.8	2016	3427	5818	9888
55	21.8	2.3	1833	3116	5289	8989
60	20	2.0	1680	2856	4848	8240
65	18.5	1.7	1551	2636	4475	7606
70	17.1	1.4	1440	2448	4155	7063
75	16	1.3	1344	2285	3878	6592
80	15	1.1	1260	2142	3636	6180
84	14.3	1	1200	2040	3463	5886

10. Grating Data (G/mm)

a. Echelle 177.5 104.4 61.6 36.2

b. Cross Disperser 2300 1360 800 470

11. Spectrum in one exposure ($\text{\AA}$) 350 600 1010 1720

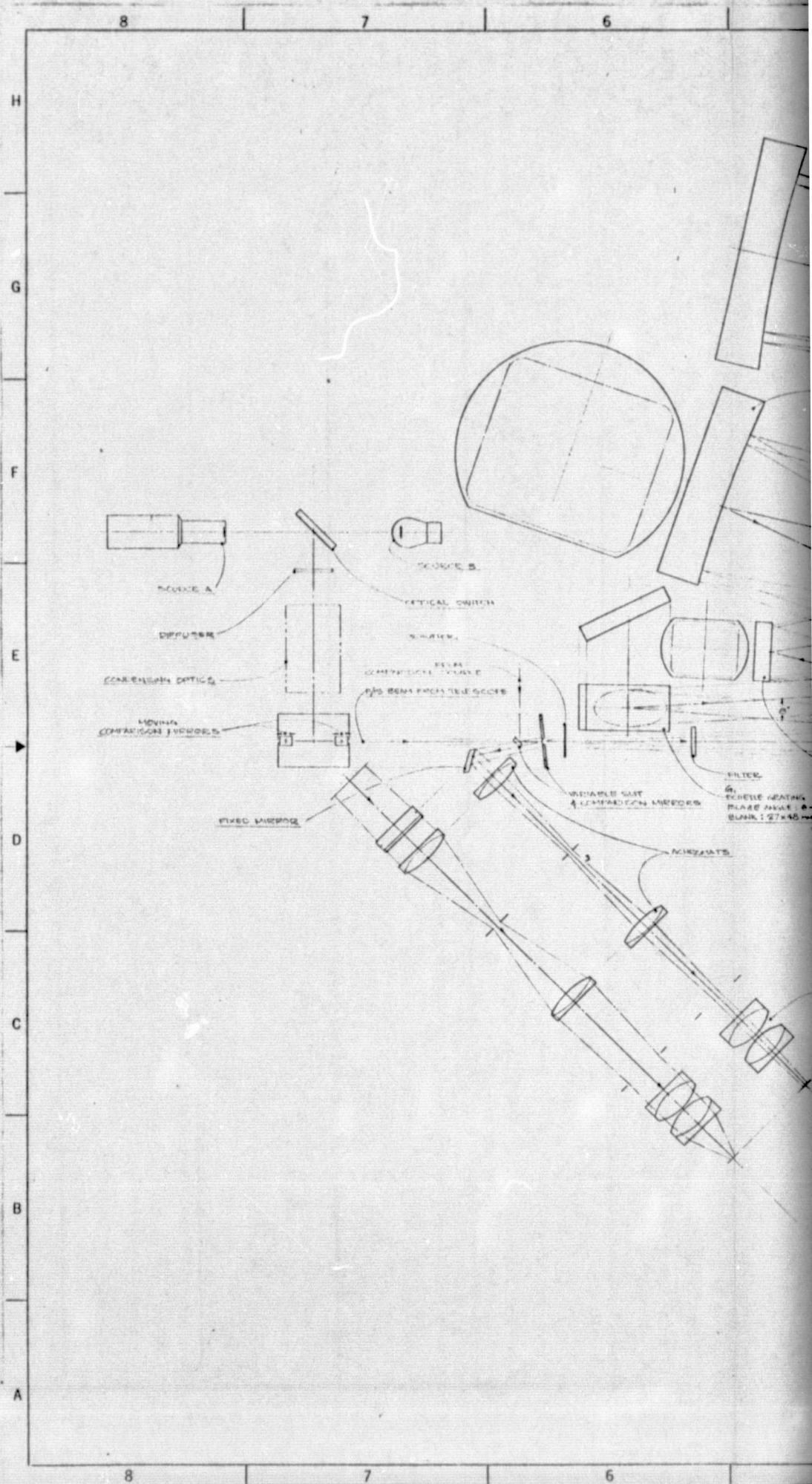
12. Blocking Filter MgF_2 Corning Corning Corning

a. Type 9-58 0-54 3-66

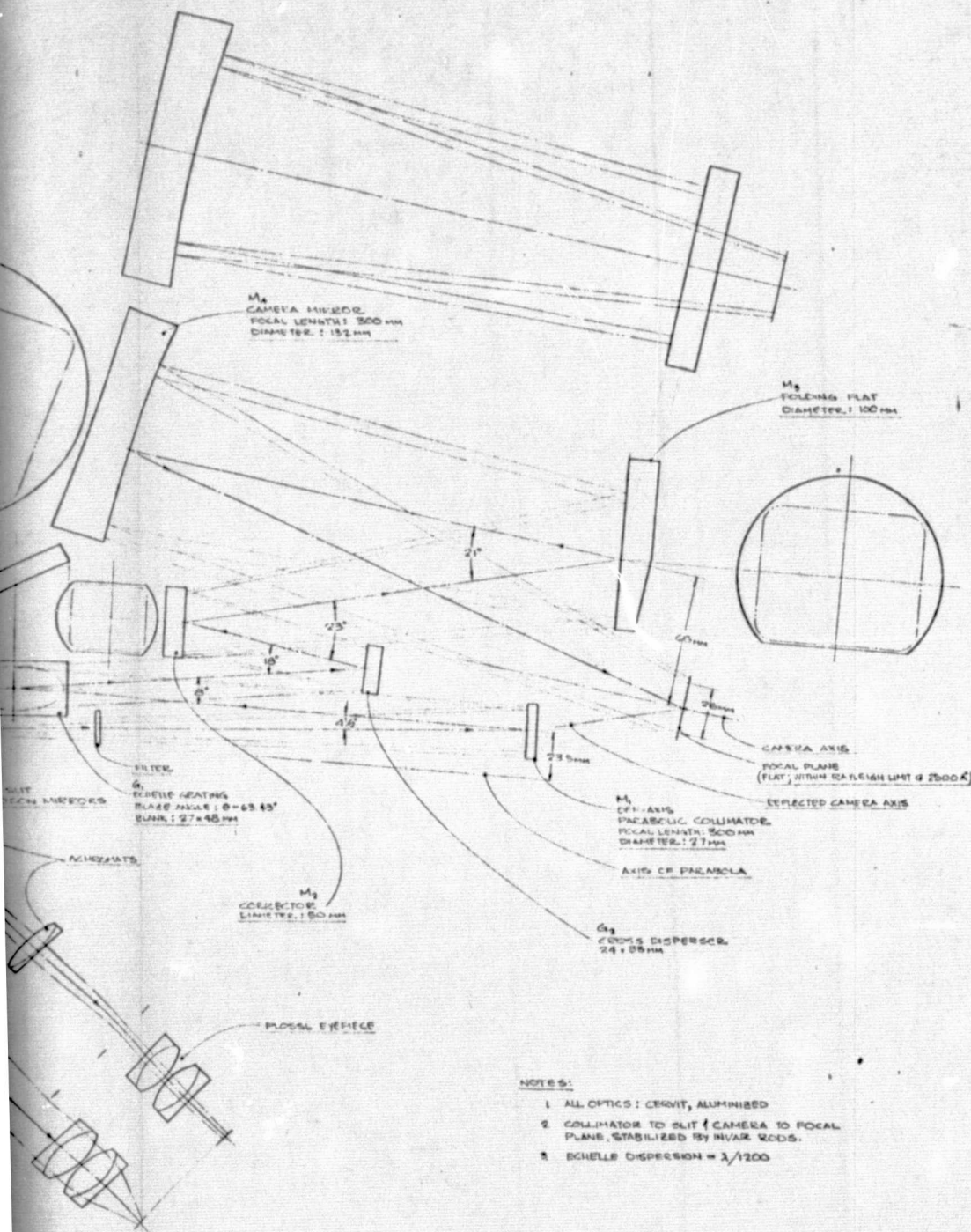
b. Short side block ($\text{\AA}$) 1100 1800 3020 5600

c. Second order of cross disperser overlaps at ($\text{\AA}$) 2200 3600 6040 1.12_μ

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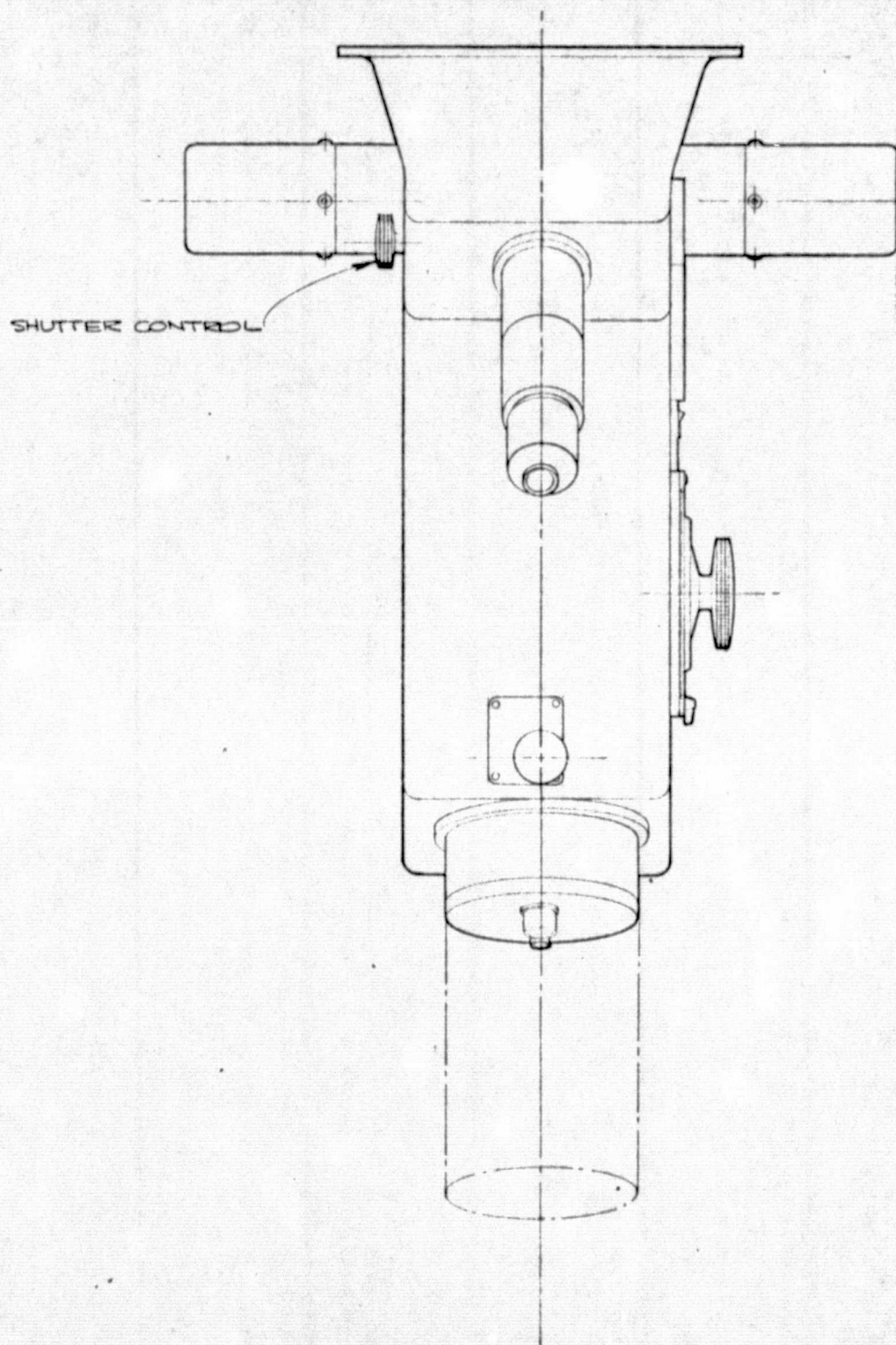


FOLDOUT FRAME 2



QTY	FOUND OR ITEM NO.	PART OR IDENTIFYING NO.	IDENTIFICATION OR DESCRIPTION	SPECIFICATION	MATERIAL OR NOTE	CODE BLOCK
LIST OF MATERIAL						
SPECIAL USE - MAKE SPECIFIED DIMENSIONS ARE IN INCHES UNLESS OTHERWISE SPECIFIED FINISHES: ☐ AS ☐ AN ☐			PERKIN ELMER BOLLER & ENGINEERS DIVISION			
WHICH END - IN OR OUT TO FACE OF PARTS - PARTS TO FACE AND IN OR OUT OF SURFACES TO BE ☐ AS			OPTICAL DIAGRAM - ECHELLE FOR AFPT			
DIM AND TOL. APPLY AFTER FINAL DRESS MATERIAL			SPECIFIC DEL. APPROVED BY APPROVED BY DATE			
			CONTACT NO.			
			ELLEN ACTIVITY APPROVAL			
			OTHER APPROVAL			
SIZE CODE IDENT NO. E 80105				45391		
SCALE FULL WT.				SHEET 1 of 1		

FOLDOUT FRAME



ACCI

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ECH
AND

SLIT

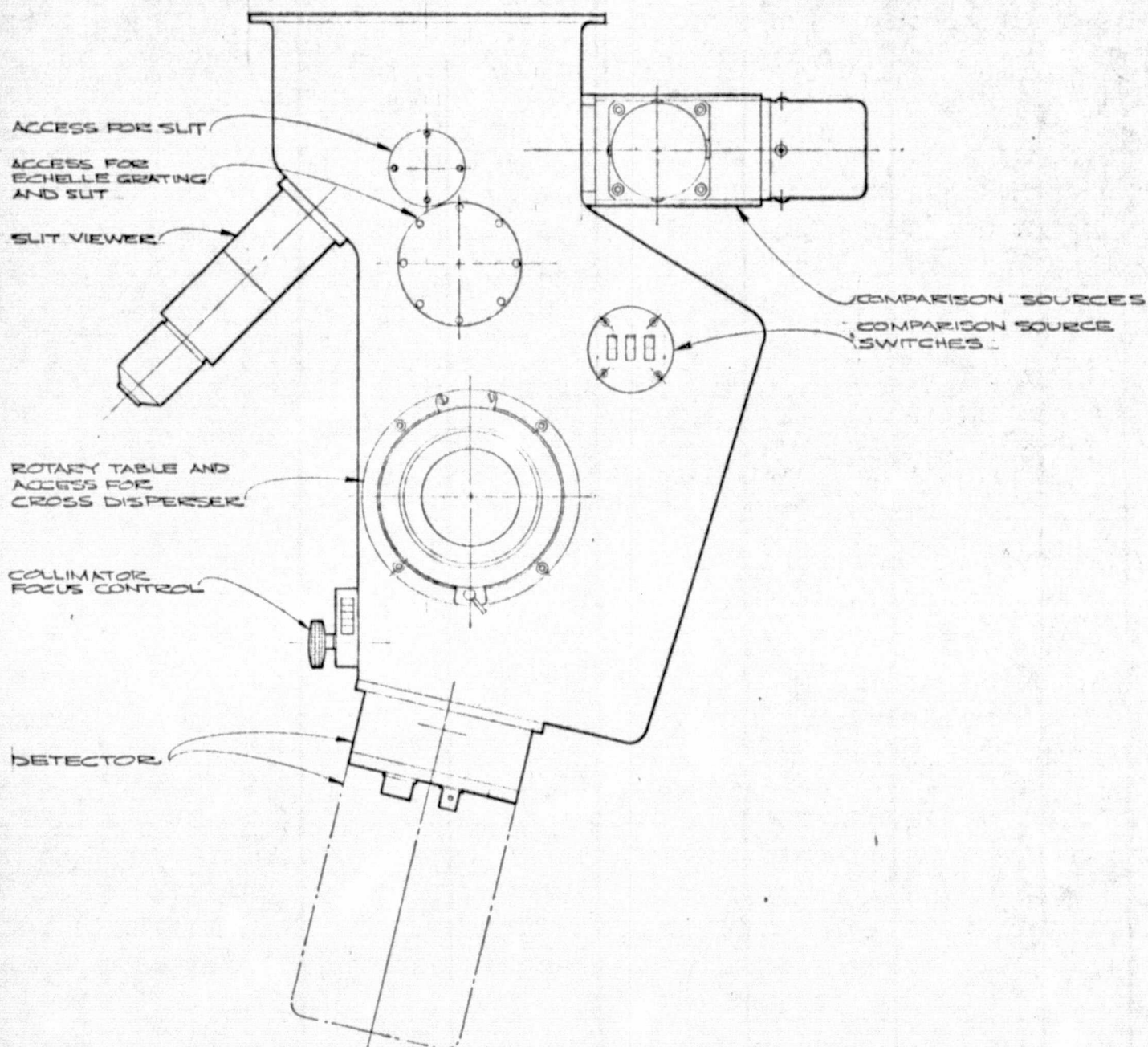
ROT
AC
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REVISIONS				DATE	APPROVED
DASH	ZONE	LTR	DESCRIPTION		

FOLDOUT FRAME 2



QTY	FIND OR ITEM NO.	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	SPECIFICATION	MATERIAL OR NOTE	CODE IDENT.
LIST OF MATERIAL						
UNLESS OTHERWISE SPECIFIED			ORIG DATE	FEB 24/76		
DIMENSIONS ARE IN INCHES			DRAFTSMAN	DEMARCEE		
FRACTIONS DECIMALS ANGLES			CHECKER	P E		
* XX * XXX *			APPROVED ASSY	PC		
MACH COR — .005 TO .015 R OR CHAM			REL	CM		
SH MATL — BREAK EDGES .005 MAX R			CONTRACT NO.			
ALL ✓ SURFACES TO BE			✓ AA			
DIM AND TOL APPLY AFTER FINAL TREAT.			DESIGN ACTIVITY APPROVAL			
MATERIAL			OTHER APPROVAL			
FINISH			SIZE	CODE IDENT NO.		
			D	80105	45389	
			SCALE	1/2	WT.	
			SHEET 1 OF 1			

JOB 59068

APPLICATION	QTY	USED ON	QTY
NEXT ASSY			

VI. Echelle Spectrograph

A. Configuration (Cont'd)

single slits of different but fixed widths and several multiple slits. All the slits are of a fixed width to simplify the instrument and enhance its reliability. A pair of comparison prisms are used to introduce comparison light into the ends of the slit (or the ends of the central slit when multiple slits are used). The comparison prism spacing is adjustable. The upper surface of the slit is highly reflective to reflect the telescopes field into the slit viewing periscope. With the comparison prisms retracted, the viewing field is a rectangle of about 10mm x 25mm (2.3 x 5.7 arc minutes).

An off-axis parabolic mirror is used to collimate the beam. The diameter of the collimated beam for a point source is 20mm. At the corner of the field, where the images are the largest, the comatic image has a spread of $10\mu\text{m}$ (0.14 arc seconds) in the direction of the echelle dispersion and $20.3\mu\text{m}$ (0.28 arc seconds) along the direction of the projected slit.

The high dispersion grating is an R-2 echelle grating (tangent of blaze angle = 2). It has a ruled area of 2.5cm x 6cm and a blank size of 2.7cm x 5.4cm x 1cm. Four echelles, one for each spectral region, are required.

VI. A. (Cont'd)

First order gratings are used to separate the echelle orders. The minimum separation is 1mm at the short wavelength limit of the spectral region and the separation increases to 3.1mm at the longer wavelength limit. The ruled area of the cross dispersers is 2.3cm x 8.5cm with an 11° blaze angle. Four cross dispersers, one for each spectral region, are also required. Table 1 lists the number of grooves per millimeter for both dispersers, for each of the four spectral regions.

A 300mm all reflecting, off-axis, folded Schmidt camera is used to image the spectrum on the detector. Although the field is curved, the visual light images formed on a flat detector, will be within the Rayleigh limit except for the extreme corners. The corrector is figured to produce a point image at the center of the field. At the corners of the field, the image spread, due to the camera's aberrations, is considerably smaller than the diffraction image in visible light. In visible light, the camera is diffraction limited, with the previously noted exception of the extreme corners of the field.

The spectrograph has several auxiliary systems.

- 1) Slit Viewer - Light reflected from the slit jaws enters a slit viewing periscope which is used to acquire the object under study and, in the case of extended objects, to assist in guiding the telescope. An image intensifier can be added to permit the viewing of very faint objects.

VI. A. (Cont'd)

- 2) Spectrum Comparison System - Several spectrum comparison sources may be provided. A final selection was not made as part of this study. The conventional iron-argon hollow cathode and neon glow lamp sources can be used for the near IR red, blue, and near UV regions. A thorium hollow cathode source may be a good selection for the UV region.

A filter holder will be placed in the comparison system.

- 3) Shutter - A blade type shutter, mounted shortly behind the slit, is used to interrupt the beam to limit the period of the exposures.
- 4) Order Separating Filters - A filter is placed behind the slit to eliminate the overlapping second order of the cross disperser. The selection of filters is shown in Table 1.
- 5) Exposure Meter - A photon-counting exposure meter could be a useful accessory to verify that the starlight is passing through the slit and to indicate the amount of accumulated exposure. Several sources of light are available including the light scattered into other orders at the echelle or the cross disperser, or a flip mirror that reflects a small amount of light into the meter.

All of the optics are mounted on an "optical table," probably made of Invar. This table is kinematically mounted so that it cannot be distorted by pressure or temperature changes in the

VI. A. (Cont'd)

space lab. The plate is defined in all three coordinates near the detector, and in two coordinates near the slit. By the use of an Invar table, and zero expansion mirrors, the optical alignment and focus is not sensitive to temperature.

A vacuum enclosure is used to enclose the entire optical path. This housing has a large removable plate for laboratory alignment purposes. Smaller access ports are provided for use in changing gratings and the order separating filters in orbit.

All the mirrors and diffraction gratings will be aluminized and overcoated with magnesium fluoride.

B. Instrument Adapter Interface

A rectangular flange is used to mount the spectrograph to the instrument adapter. A concentric pilot is provided to insure alignment of the slit at the center of the telescope's field.

C. Detectors

Several different detectors may be used, including photographic plates, electrographs, image intensifiers, CCD's, CID's, linear arrays and more conventional television type detectors. A common interface is used for all the detectors. Again, a concentric pilot will maintain alignment and an 'O' ring will seal the joint.

D. Controls

Mechanical controls are provided on the outside of the vacuum housing to operate the shutter, comparison prisms, cross disperser angle, the collimator focus and comparison source selector. Electrical switches are provided to operate the comparison sources.

VI. D. (Cont'd)

The angle of the echelle will be adjusted in the laboratory and need not be adjusted again. To change the wavelength range within a given spectral region, the angle of the cross disperser is changed. Tables or charts can be prepared to aid in the selection of the proper angle.

When detectors with an electronic readout or image intensifiers are used, the observer can adjust the focus while viewing the output. If a photographic plate or an electrograph is used, he may either accept the laboratory calibration of focus or confirm the focus by making a focus plate and develop it aboard the spacecraft.

E. Performance

Table 1 lists many of the performance characteristics of the spectrograph including the dispersion, spectral resolution, length of orders and the separation of orders.

At $f/15$, the diameter of the Airy disk varies from $4.4\mu\text{m}$ at $1200\text{\AA}$ to $38\mu\text{m}$ at $1.03\mu\text{m}$. In the center of the visible range, the diameter is $20\mu\text{m}$. Photographic plates can resolve 10 to $15\mu\text{m}$. Most photoelectric detectors resolve from 20 to $40\mu\text{m}$. In general, the resolution of the spectrograph is limited by the linear resolution of the detector, not the angular resolution of the optics.

In Section A it was pointed out that the collimator produces diffraction limited images for objects at the center of the 5mm square slit field. At the corners of the field, the image spread amounts to $10\mu\text{m}$ in the direction of the echelle dispersion and $20\mu\text{m}$ in the direction of the projected slit.

VI. E. (Cont'd)

The aberrations of the camera were also discussed in Section A. With the exception of the far corners of the field, the images are within the visual Rayleigh limit. At shorter wavelengths, the detector limits the resolution.

VII. Acceptance and Qualification Test Plan

A. Purpose

The purpose of this section of the report is to outline and identify the equipment and tests necessary to verify the acceptance and qualification of the AFPD version of the SUOT and associated equipment for flight on shuttle. The tests are outlined in two sections; acceptance tests on all experiment hardware, and qualification tests to be applied only to the qualification test unit.

B. Applicable Documents

Levels and other applicable data for the above outlined tests were determined by use of "Spacelab Payload Accommodation Handbook" marked "Preliminary" and dated May 1975 (SLP/2104). Much of the required data is in very preliminary form or TBD. Levels and other data included in this document are best estimates based on SKYLAB experience.

C. Test Configuration and Interface Fixture

Many of the tests require the complete experiment to be assembled in an operational configuration. This will require a test fixture which simulates the end cone structure of the Spacelab Module. The test fixture is mounted to a suitable adapter plate which is capable of supporting the entire AFPT facility including the modified telescope tube, the telescope mounting, the redesigned aft plate, the airlock, the instrument adapter, and the spectrograph. This test fixture should be designed to simulate all the required interfaces and should be compatible with the requirements of all the environmental tests.

VII. Acceptance and Qualification Test Plan (Cont'd)

- C. As presently envisioned, the above mentioned test fixture would be a stainless steel ring structure the diameter of the Spacelab Module. The structure would be designed to support the experiment hardware through vibration and thermal testing. The materials shall be qualified to be compatible with vacuum and thermal vacuum tests. Separate fixtures shall be made to separately qualify sub-assemblies such as the spectrograph, instrument adapter and airlock during leakage and vacuum tests.

D. Acceptance and Qualification Tests

The following tests are considered required or desirable for the AFPT hardware. Actual requirements could vary depending on future definition and completion of shuttle payload environmental tests requirements documentation.

1) Vibration

The AFPT hardware shall be subjected to vibration tests in an assembled non-operating configuration. That means the telescope will be locked into its launch and re-entry support structure and the airlock will be blocked off with its cover plate. In addition, the spectrograph and instrument adapter will be in their respective stowage structures. The environmental levels are defined by SLP/2104 Paragraph 5.1.

2) Shock

Mounted in the configuration described in D 1), the experiment hardware shall be subjected to shock tests as outlined in Section 5.1.3 of SLP/2104. This includes pyro shock TBD, loading shock as detailed in table 5-2 of SLP/2104, and crash safety shock which will be covered by static

VII. Acceptance and Qualification Test Plan (Cont'd)

D. Acceptance and Qualification Tests (Cont'd)

stress analysis. This last requirement is for equipment survival only in a non-operating condition with no loose parts.

3) Acceleration

The experiment hardware shall be subjected to acceleration tests to simulate a nominal and emergency sequence of orbital mission operations as detailed in table 5-3 of SLP/2104.

The experiment hardware shall also be subjected to the environments detailed in table 5-4 of SLP/2104 while in the free operational configuration.

4) Temperature

All airlock and airlock experiment hardware shall be subjected to temperature tests of 15° C. to 45° C. mounted in a suitable test chamber. Gas compositions and pressure is defined in table 5-6 of SPL/2104.

5) Thermal Vacuum

The telescope experiment package shall be mounted in a suitable thermal vacuum chamber in an unstowed operational configuration. All equipment control heaters shall be on during operation tests. The pressure shall be reduced to 1×10^{-6} torr with a non-contaminating pumping system. The thermal environment is defined by tables 5-9 and 5-10 of SPL/2104.

VII. Acceptance and Qualification Test Plan (Cont'd)

D. Acceptance and Qualification Tests (Cont'd)

6) EMI

To insure compatibility with the shuttle spacecraft and its sub-systems, the AFRD hardware in the operational mode shall be qualified in accordance with the Space Shuttle Amendment to MIL-STD-461A.

7) Bonding

All equipment shall have suitable coatings and bonding straps to insure bonding resistance paths not to exceed 2.5 milli ohms.

8) Optical Performance Tests

Using an ultraviolet collimator, several diverter mirrors, and a focal plane photometer, all the following optical operation parameters shall be verified in a vacuum environment of 1×10^{-6} torr.

- a) Collimation
- b) Resolution
- c) Mount guidance to ± 2 arc sec
- d) Secondary mirror guidance to $\pm .03$ arc sec
- e) Slew rate of $3^\circ/\text{sec}$
- f) Absolute pointing to ± 20 arc sec

VIII. AFPT Costing

Table 2 summarizes the expected costs for two possible AFPT funding programs. Under the first program, a single complete set of proto-flight hardware would be built which would be used as a combined prototype, qualification test, and flight unit. Under the second program, two complete sets of hardware would be built. One set would serve as a combined prototype and qualification test unit, while the second would be used as the flight hardware.

The cost figures shown in Table 2 include all the necessary engineering and qualification testing required to produce the final flight hardware.

TABLE 2

AFPT COST ANALYSIS

ITEM	CONSTRUCTION CONCEPTS	
	Protoflight (\$1000) Unit	Prototype & Flight Unit (\$1000)
Telescope Tube	1170	1919
Optics & Mountings	2215	2876
Telescope Mount	1018	1670
Scientific Airlock	16	32
Aft Plate	612	1010
Instrument Adapter	794	1302
AFPT Total	5825	9803
Spectrograph	899	1475

REFERENCES

1. Telescope Optical Design Concepts Study in Support of the Facility Definition Team

Final Report July 1975 M. Bottema, Ball Brothers Research Corporation

Contract NAS5-24048
2. Feasibility Study of the Spacelab Ultraviolet Optical Telescope Facility

Final Report October 1975 Ball Brothers Research Corp.
Contract NAS5-24048
3. Interim Report of the Facility Definition Team
Astronomy Spacelabs Payloads Study
Goddard Space Flight Center
4. Space Shuttle System Payload Accommodations
Level II Program Definition and Requirements
Volume XIV JSC 07700
Johnson Space Center
5. Spacelab Payload Accommodations Handbook, May 1975.
NASA and ESRO
6. CCD Star Trackers W. C. Goss

Proceedings of Symposium on Charge-Coupled Device
Technology for Scientific Imaging Applications
March 6-7, 1975, Jet Propulsion Laboratory
JPL SP 43-21 (p 31).

PERKIN-ELMER
BOLLER & CHIVENS DIVISION
916 MERIDIAN AVENUE
SOUTH PASADENA, CALIFORNIA 91030
TELEPHONE: (213) 682-3391

DESIGN ANALYSIS

AEPT FOR SUOT
NASA / JSC

JOB No. 59068

SHEET OF

DATE 2-27-76

BY O'Rourke

APPENDIX A INDEX

SECTION

TITLE

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SUM-1 - NATURAL FREQUENCY
SUM-2 - MAX. STRESS LEVELS
SUM-4 - CREW MOTION DISTURBANCE
SUM-7 - WEIGHTS AND CENTER OF GRAVITY
SUM-8 - DRIVE MOTOR SUMMARY
SUM-9 - ROTATION DRIVE MOTOR
SUM-13 - TILT DRIVE MOTOR
SUM-16 - INSTRUMENT ADAPTER DRIVE MOTOR

CONF-1 CONFIGURATION

DEF DEFLECTION AND SLOPE

DEF-X-1 - LOADING IN X-AXIS
DEF-Y-1 - LOADING IN Y-AXIS
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SA STRESS ANALYSIS

SA-1 - SUMMARY (COMBINED LOADS)
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SECT-1 SECTION PROPERTIES

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PERKIN-ELMER

BOLLER & CHIVENS DIVISION

916 MERIDIAN AVENUE

SOUTH PASADENA, CALIFORNIA 91030

TELEPHONE: (213) 682-3391

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SUMMARYDEFLECTION AND SLOPE AT TELESCOPE TUBE

(FROM SUPPORT CONE, 4-PT BEARING & FORK)

ADDITIONAL SUPPORT FROM THE IN-FLIGHT HARD MOUNTING TO THE CENTER RING OF THE SPACELAB AFT-CONE HAS NOT BEEN INCLUDED

	DEFLECTION AT TELESCOPE mm (IN) $\times 10^{-3}$			SLOPE AT TELESCOPE RAD (SEC OF ARC)		
	X-AXIS	Y-AXIS	Z-AXIS	X-AXIS	Y-AXIS	Z-AXIS
FORK TINES	2.5 (.099)	127.0 (5.0)	66.6 (2.6)	0	* 228×10^{-6} (47.0 $^{\circ}$)	118×10^{-6} (24 $^{\circ}$)
FORK RING	0	58.1 (2.2)	41.66 (1.6)	0	76.3×10^{-6} (15.7 $^{\circ}$)	54.67×10^{-6} (11.3 $^{\circ}$)
4-PT BEARING	2.24 (.088)	8.44 (.33)	8.44 (.33)	0	4.98×10^{-6} (1.0 $^{\circ}$)	4.98×10^{-6} (1.0 $^{\circ}$)
SUPPORT CONE	95.5 (3.8)	14.58 (.57)	14.58 (.57)	0	4.65×10^{-6} (1 $^{\circ}$)	4.65×10^{-6} (1 $^{\circ}$)
TOTAL EFFECT ON TELESCOPE	100.24 (3.9)	208.12 (8.2)	131.28 (5.2)	0	* 85.93×10^{-6} (17.7 $^{\circ}$)	182.30×10^{-6} (37.6 $^{\circ}$)

*
FORK TINES DEFLECT AS
A PARALLELOGRAM THUS
HAVING ZERO SLOPE AT TELESCOPE

NATURAL FREQUENCY OF SUPPORT SYSTEM (CONE + BEARING + FORK)

$$X-AXIS \quad f_n = 50.5 \text{ Hz}$$

$$Y-AXIS \quad f_n = 34.5 \text{ Hz}$$

$$Z-AXIS \quad f_n = 43.5 \text{ Hz}$$

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BOLLER & CHIVENS DIVISION

916 MERIDIAN AVENUE

SOUTH PASADENA, CALIFORNIA 91030

TELEPHONE: (213) 682-3391

DESIGN ANALYSISAFPT FOR SUOTNASA / JSCJOB No. 59068SHEET OFDATE 2-27-76BY D. ROURKESUMMARY (CONT)MAXIMUM STRESSES IN TELESCOPE SUPPORT SYSTEM

SINCE THE TELESCOPE TUBE SUPPORT HAS BEEN DESIGNED FOR STIFFNESS, THE NOMINAL STRESS LEVELS ARE VERY LOW. FOR THIS ANALYSIS THE FOLLOWING EXTREME CONDITIONS HAVE BEEN USED TO DETERMINE MAXIMUM STRESSES:

1. NO AUXILIARY CRADLE PROVIDED TO SUPPORT THE TELESCOPE TUBE DURING LAUNCH AND RE-ENTRY
2. DYNAMIC ACCELERATIONS ARE OCCURRING AT THE RESONANT FREQUENCY OF THE SUPPORT SYSTEM (~ 40 Hz) WITH A MECHANICAL AMPLIFICATION FACTOR OF $Q=20$. (LOW DAMPING)
3. RANDOM VIBRATIONS ARE OCCURRING AT THE RESONANT FREQUENCY OF THE SUPPORT SYSTEM (~ 40 Hz) WITH A MECHANICAL AMPLIFICATION FACTOR OF $Q=20$. (LOW DAMPING)

MAX LOADS OCCUR DURING THE FOLLOWING MISSION PHASES:

X-AXIS MAX LOAD = 41 g DURING "SOLID ROCKET CUT-OFF"

Y-AXIS MAX LOAD = 10.7 g DURING "LAUNCH RELEASE"

Z-AXIS MAX LOAD = 58.1 g DURING "LAUNCH RELEASE"

(UPDATED TO 20.1 g)

NOTE: THE ABOVE LOAD LEVELS EXCEED THE 9 g CRASH LANDING LOAD IN THE +X DIRECTION.

(CONT)

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916 MERIDIAN AVENUE

SOUTH PASADENA, CALIFORNIA 91030

TELEPHONE: (213) 682-3391

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SUMMARY (CONT)MAX. STRESSES IN TELESCOPE SUPPORT SYSTEM (CONT)

MAX COMBINED STRESS IN: $f_b = \sqrt{f_x^2 + f_y^2 + f_z^2}$

1. SUPPORT CONE $f_b = \frac{1.14 \times 10^8 \text{ N/m}^2}{(16,500 \text{ LB/IN}^2)}$

DURING "SOLID ROCKET CUT-OFF"

$\Sigma X = 41.9$

$\Sigma Y = 5.59$

$\Sigma Z = 8.19$

MARGIN OF SAFETY = 1.79

2. 4 PT CONTACT BEARING

AXIAL LOAD $F_A = \frac{2.19 \times 10^5 \text{ N}}{(49,200 \text{ LB})}$

DURING "SOLID ROCKET CUT-OFF"

M.S. = 3.05

RADIAL LOAD $F_R = \frac{3.16 \times 10^5 \text{ N}}{(70,935 \text{ LB})}$

DURING "LAUNCH RELEASE"

M.S. = -0.02 (UPDATED TO +1.54)

MOMENT LOAD $M = \frac{2.81 \times 10^5 \text{ N.M}}{(2,480,000 \text{ LB.IN})}$

DURING "LAUNCH RELEASE"

M.S. = -0.38 (UPDATED TO +0.82)

3. FORK RING

$f_b = \sqrt{f_x^2 + f_y^2 + f_z^2}$

$\Sigma X = 12.59$

$\Sigma Y = 10.79$

$\Sigma Z = 58.19$

$f_b = \frac{1.19 \times 10^8 \text{ N/m}^2}{17,261 \text{ LB/IN}^2}$

DURING "LAUNCH RELEASE"

M.S. = 1.66

4. FORK TINES

$\Sigma X = 12.59$

$\Sigma Y = 10.79$

$\Sigma Z = 58.19$

$f_b = \frac{2.71 \times 10^8 \text{ N/m}^2}{39,240 \text{ LB/IN}^2}$

DURING "LAUNCH RELEASE"

M.S. = 0.17

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916 MERIDIAN AVENUE

SOUTH PASADENA, CALIFORNIA 91030

TELEPHONE: (213) 682-3391

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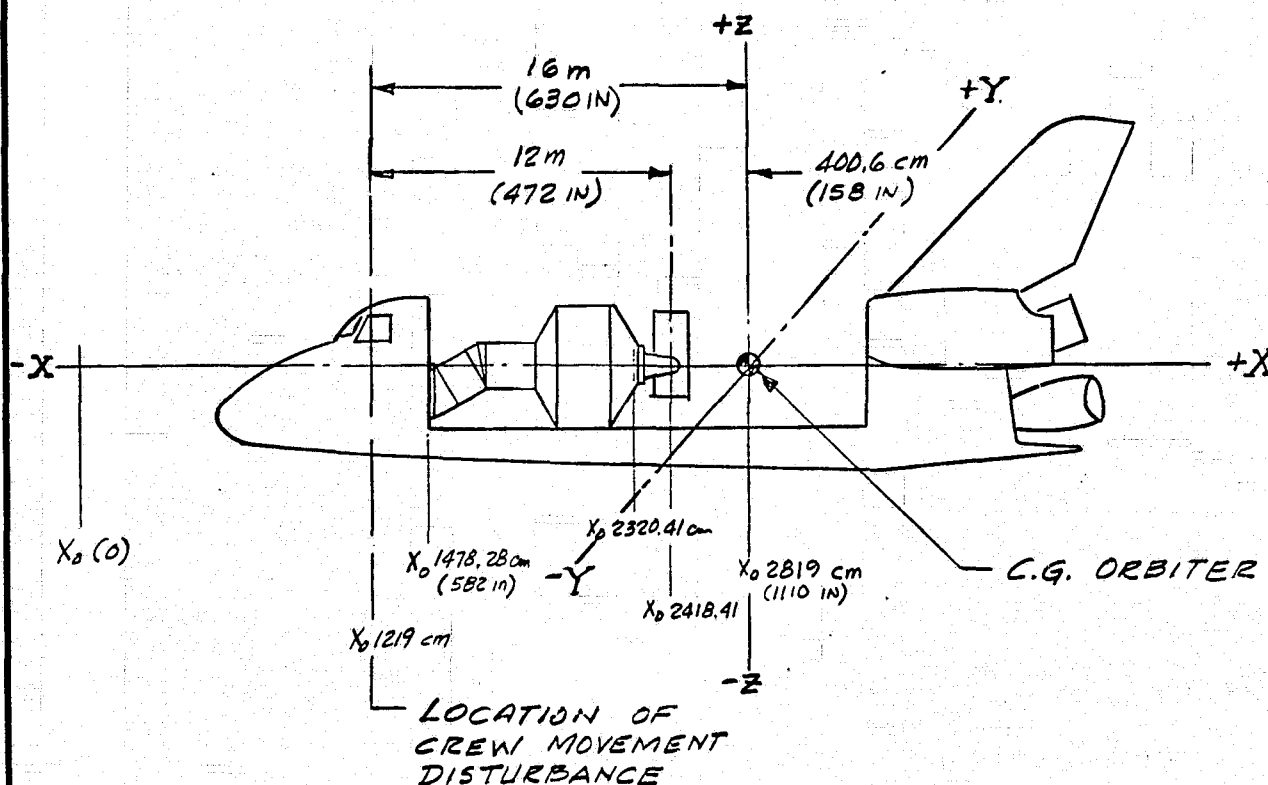
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CREW MOTION DISTURBANCE - RESULTING POINTING ERROR FROM DEFLECTION OF TELES. MOUNT ONLY

AVERAGE FORCE DUE TO CREW MOVEMENT $F_D = 50 \text{ N}$ (11.24 LB)
(LOCATED 16m FORWARD OF C.G. IN X-AXIS)

MOMENT OF INERTIA OF ORBITER + SPACELAB

TABLE 2-1

$I_{x-x} = 1.034 \times 10^6 \text{ Kg} \cdot \text{m}^2$ (1.76 SLUG FT²)
 $I_{y-y} = 7.643 \times 10^6 \text{ Kg} \cdot \text{m}^2$ (5.6 SLUG FT²)
 $I_{z-z} = 7.838 \times 10^6 \text{ Kg} \cdot \text{m}^2$ (5.8 SLUG FT²)

ORBITER FORCED ACCELERATION

$\alpha_{xx} = \frac{T}{I_{xx}} = \frac{50 \times 0 \text{ m}}{1.034 \times 10^6 \text{ Kg} \cdot \text{m}^2} = 0.00 \frac{\text{RAD}}{\text{SEC}^2}$
 $\alpha_{yy} = \frac{T}{I_{yy}} = \frac{50 \times 16}{7.643 \times 10^6} = 1.05 \times 10^{-4} \frac{\text{RAD}}{\text{SEC}^2}$
 $\alpha_{zz} = \frac{T}{I_{zz}} = \frac{50 \times 16}{7.838 \times 10^6} = 1.02 \times 10^{-4} \frac{\text{RAD}}{\text{SEC}^2}$

(CONT)

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BOLLER & CHIVENS DIVISION

916 MERIDIAN AVENUE

SOUTH PASADENA, CALIFORNIA 91030

TELEPHONE: (213) 682-3391

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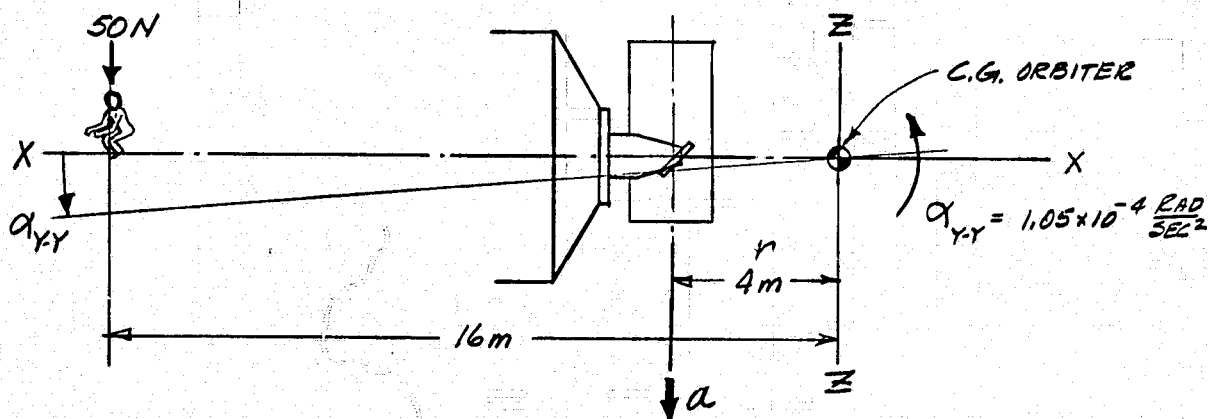
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CREW MOTION DISTURBANCE - (CONT)

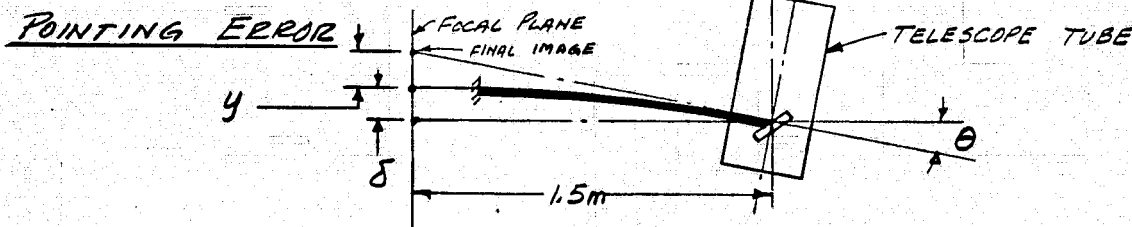
CREW MOTION DISTURBANCE IN THE X-Z PLANE WILL PRODUCE DEFLECTIONS OF THE TELESCOPE TUBE SUPPORT STRUCTURE AND THUS POINTING ERROR. (FOR SMALL TILT ERRORS THE IMC WILL MAKE NECESSARY CORRECTIONS.)

POINTING ERROR FROM CREW MOTION IN X-Z PLANEACCELERATION OF TELESCOPE TUBE

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR

$$a = r \alpha_{Y-Y} = 4 (1.05 \times 10^{-4}) = 4.2 \times 10^{-4} \text{ m/SEC}^2$$

$$= \frac{4.2 \times 10^{-4} \text{ m/SEC}^2}{9.8 \text{ m/SEC}^2/g} = .000,0429 g$$



$$\delta' = \text{DEFLECTION FROM } 1g \text{ LOAD (SEE DEFLECTION CALCS)} = 142.94 \times 10^{-6} \text{ m/g } (.0056 \text{ in/g})$$

$$\delta = \text{DEFLECTION FROM CREW MOTION } (.000,0429g) = 4.29 \times 10^{-5} g (1.43 \times 10^{-4} \text{ m/g}) = 6.13 \times 10^{-9} \text{ m } (.0006 \mu)$$

$$\theta' = \text{ROTATION FROM } 1g \text{ LOAD (SEE DEFLECTION CALCS)} = 1.96 \times 10^{-4} \text{ RAD/g}$$

$$\theta = \text{ROTATION FROM CREW MOTION } (.000,0429g) = 4.29 \times 10^{-5} g (1.96 \times 10^{-4} \text{ RAD/g}) = 8.41 \times 10^{-9} \text{ RAD } (.0017^\circ)$$

$$\Delta = \text{GROSS IMAGE DISPLACEMENT FROM POINTING ERROR } (\theta) = \text{PLATE SCALE} \times \theta$$

$$= 4.85 \times 10^{-6} \frac{\text{RAD}}{\text{SEC}^2 \text{ ARC}} \times 15,000 \text{ mm} \times .0017^\circ = .0727 \frac{\text{mm}}{\pi} \times .0017^\circ = .000,12 \text{ mm } (.12 \mu)$$

$$y = \text{NET IMAGE DISPLACEMENT FROM POINTING ERROR} = .000,12 \text{ mm} - .000,006 = .000,12 \text{ mm}$$

POINTING
ERROR } 5

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BOLLER & CHIVENS DIVISION

916 MERIDIAN AVENUE

SOUTH PASADENA, CALIFORNIA 91030

TELEPHONE: (213) 682-3391

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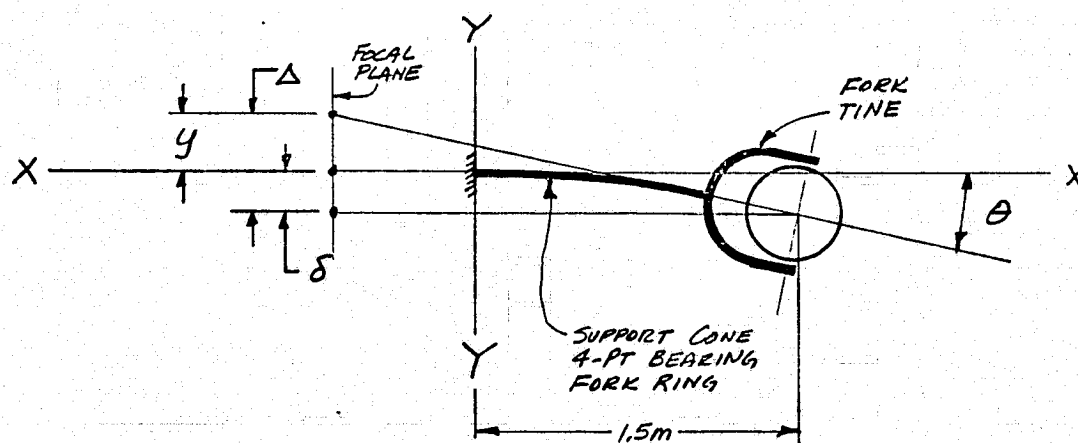
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CREW MOTION DISTURBANCE (CONT)IMAGE DISPLACEMENT FROM CREW MOTION X-Y PLANE

CREW MOTION DISTURBANCE IN THE X-Y PLANE
WILL PRODUCE PARALLELOGRAM DEFLECTION OF THE
TELESCOPE TUBE FORK TINES AND SLIGHT BENDING
OF THE SUPPORT STRUCTURE ROTATION AXIS.



$$\delta' = \text{DEFLECTION FROM } 1g \text{ LOAD (SEE DEFLECTION CALCS)} = 2.19 \times 10^{-4} \text{ m} (0.0086 \text{ in})$$

$$\delta = \text{DEFLECTION FROM CREW MOTION } (0.000,0429g) = 4.29 \times 10^{-5} \times 2.19 \times 10^{-4} \text{ m} = 9.39 \times 10^{-9} \text{ m}$$

$$\theta' = \text{ROTATION FROM } 1g \text{ LOAD (SEE DEFLECTION CALCS)} = 9.99 \times 10^{-5} \text{ RAD}$$

$$\theta = \text{ROTATION FROM CREW MOTION } (0.000,0429g) = 4.29 \times 10^{-5} \times (9.99 \times 10^{-5} \text{ RAD}) = 4.28 \times 10^{-9} \text{ RAD} \\ (0.00088^\circ)$$

$$\Delta = \text{GROSS IMAGE DISPLACEMENT} = \theta \times 1.5 \text{ m} = 6.42 \times 10^{-9} \text{ m} (2.53 \times 10^{-7} \text{ in})$$

$$y = \text{NET IMAGE DISPLACEMENT} = \Delta - \delta = 6.42 \times 10^{-9} - 9.39 \times 10^{-9} = -2.97 \times 10^{-9} \text{ m} \\ (0.003 \mu) \\ (\text{NEGLECT})$$

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BOLLER & CHIVENS DIVISION

916 MERIDIAN AVENUE

SOUTH PASADENA, CALIFORNIA 91030

TELEPHONE: (213) 682-3391

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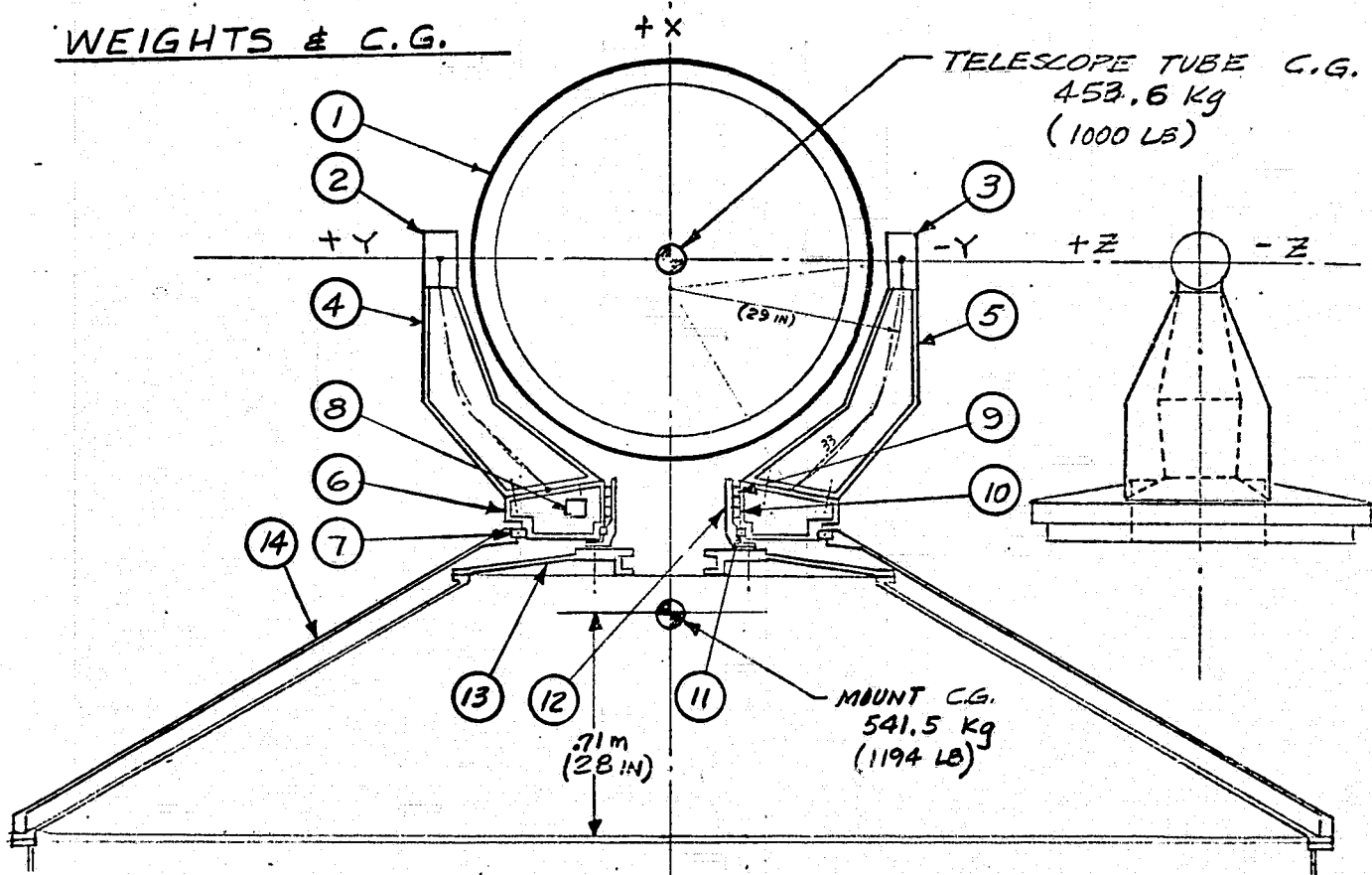
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WEIGHTS & C.G.


ITEM	NAME	WEIGHT	
		kg	LB
1	TELESCOPE TUBE	453.6	1000
2	TILT DRIVE + BRG	6.8	15
3	TILT BEARING	4.5	10
4	TINE	15.9	35
5	TINE	15.9	35
6	FORK RING	99.8	220
7	MOMENT BRG.	22.7	50
8	ENCODER ASSY	4.5	10
9	TACHOMETER	3.6	8
10	MOTOR	6.8	15
11	BEARING	5.4	12
12	HOUSING	67.6	149
13	AFT CONE HEAD	34.0	75
14	SUPPORT CONE	254.0	560
		995.1	2194

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BOLLER & CHIVENS DIVISION

916 MERIDIAN AVENUE

SOUTH PASADENA, CALIFORNIA 91030

TELEPHONE: (213) 682-3391

DESIGN ANALYSISA/EPT FOR SUOTNASA / JSCJOB No. 59068SHEET OF DATE 2-27-76BY O'ROURKEDRIVE MOTOR SUMMARYFIGURE

	ROTATION DRIVE	TILT DRIVE	INSTRUMENT ADAPTER DRIVE
MOTOR PEAK TORQUE	2 @ 22 = 44 (LB-FT)	14 LB-FT	200 OZ-IN (1.04 LB-FT)
BEARING AND/OR SEAL FRICTION	16 LB-FT	.25 LB-FT	6270 OZ-IN (32.6 LB-FT)
MAX TRACKING RATE	4 °/MIN.	4 °/MIN	.077 °/SEC
POWER TO TRACK	188 WATTS	.081 WATTS	15 WATTS
AVE POWER REQD. TO ACCEL. TO TRACK RATE (APPROX.)	444 WATTS	127.5 WATTS	67.5 WATTS (.05 m SEC)
MAX SLEWING RATE	5 °/SEC	5 °/SEC	
POWER TO SLEW	190 WATTS	.11 WATTS	
AVE POWER REQD. TO ACCEL. TO SLEW RATE (APPROX)	445 WATTS (.6 SEC)	127.5 WATTS (1.1 SEC)	
MAX ACCEL. AVAILABLE	8.3 °/SEC ²	4.6 °/SEC ²	1363 °/SEC ²
NOTE :	DIRECT DRIVE MOTOR	DIRECT DRIVE MOTOR	100:1 GEAR RATIO

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BOLLER & CHIVENS DIVISION
916 MERIDIAN AVENUE
SOUTH PASADENA, CALIFORNIA 91030
TELEPHONE: (213) 682-3391

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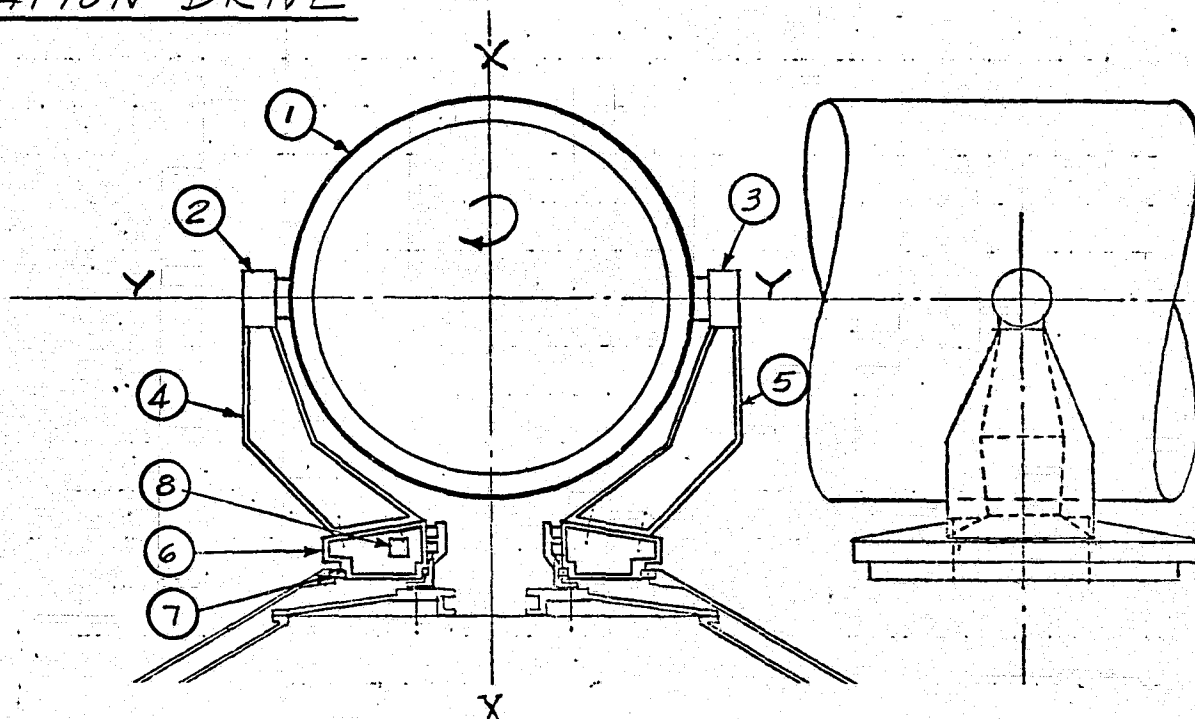
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ROTATION DRIVE



INERTIA TORQUE ABOUT X-AXIS

ELEMENT	NAME	WEIGHT (LB)	K^2 (FT ²)	WK^2 (LB-FT ²)
1	TELESCOPE TUBE	1000	5.50	5506
2	TILT DRIVE+BRG	15	6.04	91
3	TILT BEARING	10	5.25	53
4	TINE	35	3.20	112
5	TINE	35	3.20	112
6	FORK RING	220	1.41	310
7	MOMENT BRG (1/2)	25	2.54	64
8	ENCODER+BRK	10	1.00	10
		1350 LB		6258

MOMENT OF INERTIA

$$I_{X-X} = \frac{WK^2}{32.2} = \frac{6258}{32.2} = 194 \text{ LB-FT-SEC}^2$$

ACCELERATION

FROM TABLE 5-4 REF. 1 MAX ACCEL. FROM LARGE THRUSTER FIRING
 $\alpha = 1.46^\circ/\text{SEC}^2$ (.0255 RAD/SEC²) ϕ ROLL

TORQUE TO ACCELERATE

$$T = I\alpha = 194 \text{ LB-FT-SEC}^2 \times .0255 \text{ RAD/SEC}^2 = 4.95 \text{ LB-FT}$$

(CONT)

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TELEPHONE: (213) 682-3391

DESIGN ANALYSISAFPT FOR SUOTNASA/JSCJOB NO. 5906PSHEET OF DATE 2-27-76BY O'RourkeROTATION DRIVE (CONT)MOMENT BEARING FRICTION TORQUE *

- | | <u>FRICTION
TORQUE</u> |
|---|----------------------------|
| 1. PRELOAD ONLY (1,000 LB-IN) ————— | 15 LB-FT |
| 2. MOMENT + RADIAL —————
(1000 LB 24,000 LB-IN) | 16 LB-FT |
| 3. AXIAL ONLY —————
(1000 LB) | 8.4 LB-FT |

* FROM: KAYDON BEARING CO FOR
4 PT BEARING NO. 6684-1

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916 MERIDIAN AVENUE

SOUTH PASADENA, CALIFORNIA 91030

TELEPHONE: (213) 682-3391

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BY O ROURKE

ROTATION DRIVE MOTOR

2 MOTORS USED IN PARALLEL

MAGNETIC TECHNOLOGY MODEL 12250-160 22-LB-FT (EA.)
44 LB-FT TOTAL

PEAK TORQUE $T_p = 21.875 \text{ LB-FT/MOTOR}$

MOTOR CONSTANT $K_m = 1.17 \frac{\text{LB-FT}}{\sqrt{\text{WATT}}/\text{MOTOR}}$

RESISTANCE $R_m = 1.7 \Omega/\text{MOTOR}$

VOLTAGE AT T_p $V_p = 24.5 \text{ VOLT/MOTOR}$

TORQUE SENSITIVITY $K_t = 1.52 \frac{\text{LB-FT}}{\text{AMP}}/\text{MOTOR}$

BACK EMF $K_b = 2.0 \text{ VOLTS/RAD/SEC/MOTOR}$

POWER AT PEAK TORQUE $P_p = 350 \text{ WATTS/MOTOR}$

BEAR. FRICTION TORQUE = 16 LB-FT

MAX TRACKING RATE = $4^\circ/\text{min} = .00116 \text{ rad/sec}$

MAX SLEW RATE = $5^\circ/\text{sec} = .0872 \text{ rad/sec}$

TORQUE AVAILABLE TO ACCELERATE $T_a = 44 - 16 = 28 \text{ LB-FT}$

MAX ACCELERATION AVAILABLE $\alpha_{\text{MAX}} = \frac{T_a}{J_x} = \frac{28}{194 \text{ LB-FT-SEC}^2} = .144 \text{ RAD/SEC}^2$
(MAX REQUIRED = $1.46^\circ/\text{SEC}^2$) $= 8.3^\circ/\text{SEC}^2$
POWER REQUIRED TO TRACK AT $4^\circ/\text{min}$ (OVERCOME BEG FRICTION)

BACK EMF = $.00116 \text{ RAD/SEC} \times 2 \text{ VOLT/RAD/SEC} = .0023 \text{ VOLT}$

CURRENT FOR $\overset{\text{BEG. FRICTION}}{16 \text{ LB-FT}}$ $I_a = \frac{16 \text{ LB-FT}}{1.52 \text{ LB-FT/AMP}} = 10.53 \text{ AMP}$

VOLTAGE $V = I_a \times R_m = 10.53 \times 1.7 = 17.89$

TOTAL VOLTAGE $V_t = .0023 + 17.89 = 17.89 \text{ VOLTS}$

POWER = $10.53 \text{ AMP} \times 17.89 \text{ VOLTS} = \underline{188 \text{ WATTS}}$
POWER REQUIRED TO SLEW AT $5^\circ/\text{SEC}$ (OVERCOME BEG. FRICTION)

BACK EMF = $.0872 \text{ RAD/SEC} \times 2 \text{ V/RAD/SEC} = .174 \text{ VOLTS}$

CURRENT FOR $\overset{\text{BEG. FRICTION}}{16 \text{ LB-FT}}$ $I_a = \frac{16}{1.52} = 10.53 \text{ AMP}$

VOLTAGE $V = I_a \times R_m = 10.53 \times 1.7 = 17.89$

TOTAL VOLTAGE $V_t = .174 + 17.89 = 18.06 \text{ VOLTS}$

POWER = $10.53 \text{ AMP} \times 18.06 = \underline{190 \text{ WATTS}}$

(CONT.)

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916 MERIDIAN AVENUE

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TELEPHONE: (213) 682-3391

DESIGN ANALYSISAFPT FOR SUOTNASA / JSCJOB No. 5906PSHEET OF DATE 2-27-76BY O'RourkeROTATION DRIVE MOTOR (CONT)

4°/MIN

AVERAGE POWER REQUIRED TO ACCELERATE TO TRACK SPEED

PEAK TORQUE POWER $P_p = 2 @ 350 \text{ WATTS} = 700 \text{ WATTS}$
 (2 MOTORS @ STALL)

POWER REQUIRED TO TRACK AT 4°/MIN = 188 WATTS

AVERAGE POWER TO ACCEL. $P_{AVE} = \frac{700 - 188}{2} + 188 = \underline{\underline{444 \text{ WATTS}}}$
 (APPROX)

5°/SEC

AVERAGE POWER REQUIRED TO ACCELERATE TO SLEW SPEED

POWER REQUIRED TO SLEW AT 5°/SEC = 190 WATTS

AVERAGE POWER TO ACCEL. $P_{AVE} = \frac{700 - 190}{2} + 190 = \underline{\underline{445 \text{ WATTS}}}$
 (APPROX.) (FOR .6 SEC)
 SEE BELOW

MINIMUM TIME TO ACCELERATE TO SLEW SPEED (5°/SEC)

MAX ACCELERATION RATE $\alpha_{max} = 8.3^\circ/\text{SEC}^2$ (SEE PRECEDING PAGE)

MIN. TIME TO ACCEL. $t_{min} = \frac{\omega}{\alpha} = \frac{5^\circ/\text{SEC}}{8.3^\circ/\text{SEC}^2} = \underline{\underline{.6 \text{ SEC}}}$

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DESIGN ANALYSIS

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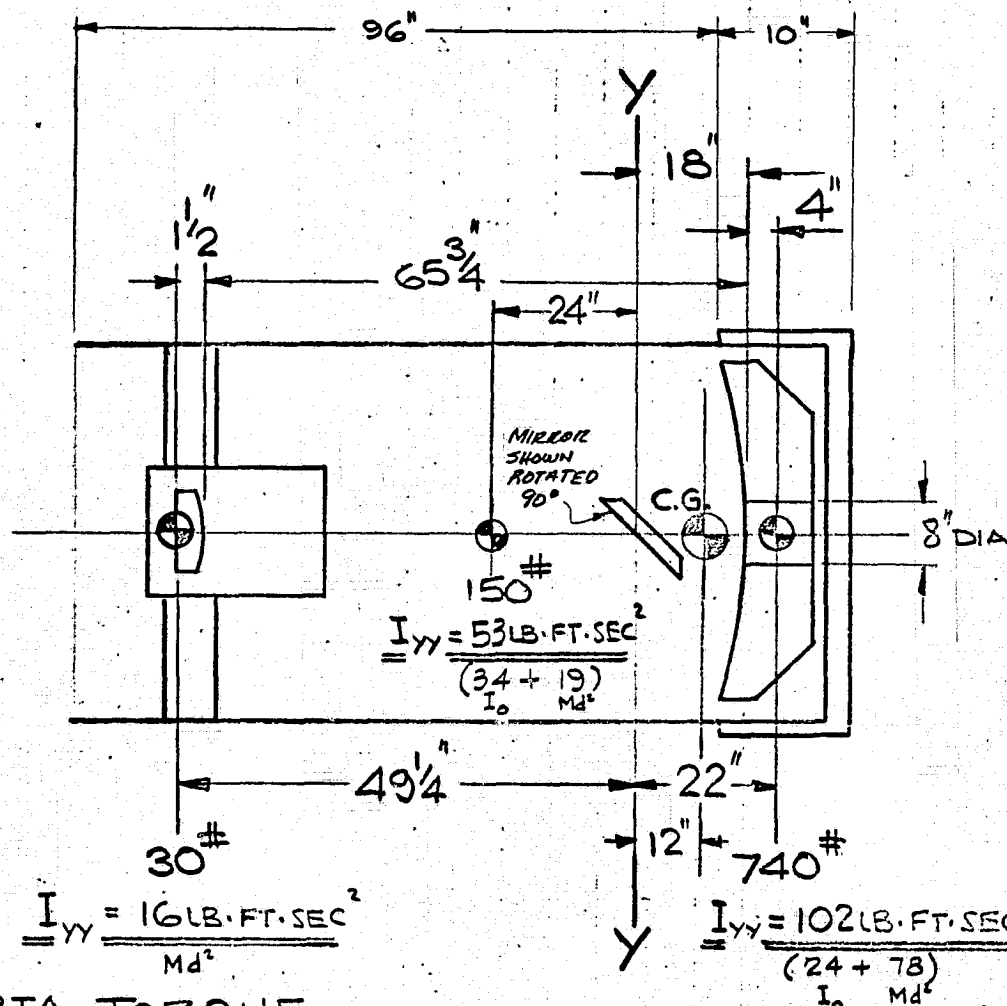
JOB No. 5906P

SHEET OF

DATE 2-27-76

BY WILLIS

TILT DRIVE



INERTIA TORQUE

$$\text{TOTAL } I_{yy} \approx 171 \text{ LB. FT. SEC}^2$$

$$\text{ACCEL}(\alpha) = 2.05^\circ/\text{SEC}^2 \text{ (}.0358 \text{ RAD/SEC}^2\text{)} \text{ (TABLE 5-4)}$$

$$\text{VEL.} = 4^\circ/\text{MIN.}$$

$$\text{TORQUE REQD} = I \alpha$$

$$= \underline{6.1 \text{ LB. FT.}}$$

$$\text{WT. (TOTAL)} \approx 1000 \text{ LB}$$

REPRODUCIBILITY OF THE
ORIGINAL PAGE IS POOR

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JOB NO. 59068

SHEET OF

DATE 2-27-76

BY D'ROURKE

TILT DRIVE MOTOR

INLAND TORQUE MOTOR T-5745 1416-FT

PEAK TORQUE $T_p = 14 \text{ LB-FT}$ MOTOR CONSTANT $K_m =$ RESISTANCE $R_m = 1.4 \Omega$ VOLTAGE AT T_p $V_p = 18.9 \text{ VOLTS}$ SENSITIVITY $K_T = 1.04 \frac{\text{LB-FT}}{\text{AMP}}$ BACK EMF $K_B = 1.41 \text{ V/RAD/SEC}$ POWER @ PEAK TORQUE $P_p = 255 \text{ WATTS}$ BEARING FRICTION $\approx .25 \text{ LB-FT}$ INERTIA $J_f = 171 \text{ LB-FT-SEC}^2$ MAX TRACK RATE $\omega_t = 4^\circ/\text{min} \quad (.00116 \text{ RAD/SEC})$ MAX SLEW RATE $\omega_s = 5^\circ/\text{SEC} \quad (.0872 \text{ RAD/SEC})$ TORQUE AVAIL TO ACCELERATE $T = 14 - .25 = 13.75 \text{ LB-FT}$ MAX ACCEL AVAILABLE $\alpha = T/J_f = 13.75/171 \text{ LB-FT-SEC}^2 = .080 \text{ RAD/SEC}^2$
 $4.6^\circ/\text{SEC}^2$ POWER REQUIRED TO TRACK AT $4^\circ/\text{min}$ (OVERCOME FRICTION)BACK EMF $V_B = .00116 \times 1.41 \text{ V/RAD/SEC} = .0016 \text{ VOLTS}$ CURRENT FOR $.25 \text{ LB-FT}$ $I_A = \frac{.25 \text{ LB-FT}}{1.04 \frac{\text{LB-FT}}{\text{AMP}}} = .24 \text{ AMP}$ VOLTAGE $V_A = I_A R_m = .24 (1.4) = .336 \text{ VOLTS}$ TOTAL VOLTAGE $V_T = V_B + V_A = .0016 + .336 = .338 \text{ VOLTS}$ POWER $P = V_T \times I_A = .338 \times .24 = .081 \text{ WATTS}$ POWER REQUIRED TO SLEW AT $5^\circ/\text{SEC}$ OVERCOME FRICTION $V_B = .0872 \text{ RAD/SEC} \times 1.41 \text{ V/RAD/SEC} = .123 \text{ VOLTS}$ $I_A = .25 \text{ LB-FT} / 1.04 \frac{\text{LB-FT}}{\text{AMP}} = .24 \text{ AMP}$ $V_A = I_A \times R_m = .24 \times 1.4 = .336 \text{ VOLTS}$ $V_T = V_B + V_A = .123 + .336 = .459 \text{ VOLTS}$ $P = V_T \times I_A = .459 \times .24 = .11 \text{ WATTS}$

(CONT.)

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SHEET ____ OF ____

DATE 2-27-76

BY O'Rourke

TILT DRIVE MOTOR (CONT)Ave Power Required To Accelerate To Track Speed (4°/min)PEAK TORQUE POWER $P_p = 255$ WATTS
(STALL)POWER REQUIRED TO TRACK AT 4°/MIN = .081 WATTS
(SEE PRECEDING PAGE)AVE POWER TO ACCEL $P_{AVE} = \frac{255 - .081}{2} + .081 = \underline{\underline{127.5 \text{ WATTS}}}$
(APPROX.)Ave Power Required To Accelerate To Slew Speed (5°/sec)

POWER REQUIRED TO SLEW AT 5°/SEC = .11 WATTS

AVE POWER TO ACCEL $P_{AVE} = \frac{255 - .11}{2} + .11 = \underline{\underline{127.5 \text{ WATTS}}}$
(FOR 1.1 SEC)
SEE BELOWMINIMUM TIME TO ACCELERATE TO SLEW SPEED (5°/sec)MAX. ACCEL. RATE $\alpha_{MAX} = 4.6 \text{ } ^\circ/\text{SEC}^2$ (SEE PRECEDING PAGE)MIN. TIME TO ACCEL $t_{MIN} = \frac{W}{\alpha} = \frac{5^\circ/\text{SEC}}{4.6^\circ/\text{SEC}^2} = \underline{\underline{1.1 \text{ SEC}}}$
TO SLEW RATE

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DESIGN ANALYSISAFPT FOR SUOTNASA / JSCJOB No. 59068SHEET OF DATE 2-27-76BY O'RourkeINSTRUMENT ADAPTER DRIVE MOTOR

MOTOR - INLAND "TORQUE-TACH" No. TT-1810

PEAK TORQUE

$$T_p = 200 \text{ OZ-IN}$$

POWER @ T_p

$$P_p = 120 \text{ WATT}$$

MOTOR CONSTANT

$$K_m = 18.3 \text{ OZ-IN}/\sqrt{\text{WATT}}$$

VOLTAGE AT T_p

$$V_p = 27.5 \text{ VOLTS}$$

RESISTANCE

$$R_m = 6.4 \text{ OHMS}$$

TORQUE SENSITIVITY

$$K_t = 47 \text{ OZ-IN/AMP}$$

BACK EMF

$$K_B = .332 \text{ V/RAD/SEC}$$

NO LOAD SPEED

$$\omega_m = 210 \text{ RAD/SEC} \quad (3.66 \text{ RPS} = 220 \text{ RPM})$$

CONTIN. STALL TORQUE

$$T_c = 72$$

ADAPTER FRICTION TORQUE

$$\text{SEALS (3 "O"RINGS @ 130 IN-LB EA)} \quad T_S = 3 \times 130 \times 16 = 6240 \text{ OZ-IN}$$

$$4\text{-PT BEARING (KAYDON KDO90XP3)} \quad T_B = 30 \text{ OZ-IN}$$

MAX TRACK RATE (COMBINE FREE & ORBITAL DRIFT)

$$.01 \text{ \% / SEC} \quad \text{FREE DRIFT}$$

$$.067 \text{ \% / SEC} \quad \text{ORBITAL DRIFT}$$

$$.077 \text{ \% / SEC} \quad (= .000,214 \text{ REV/SEC} = .0128 \text{ RPM} = .00134 \text{ RAD/SEC})$$

$$\text{GEAR RATIO} = 100:1$$

MOTOR TORQUE REQUIRED TO OVERCOME FRICTION

$$T_F = \frac{\overset{\text{SEALS}}{6240} + \overset{\text{BRG}}{30}}{100 \times \overset{\text{GEAR EFFY}}{.96^3}} = \frac{6270}{100 \times .88} = \underline{\underline{70.9 \text{ OZ-IN}}}$$

MOTOR TORQUE AVAILABLE TO ACCELERATE

$$T_A = \overset{\text{PEAK}}{200} - \overset{\text{FRICTION}}{70.9} = 129 \text{ OZ-IN AT MOTOR}$$

$$= 129 \times 100 \times .96^3 = 11,352 \text{ OZ-IN AT ADAPTER CENTER LINE}$$

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DESIGN ANALYSISAFPT FOR SUOTNASA /JSCJOB No. 59068SHEET OF DATE 2-27-76BY O'ROURKEINSTRUMENT ADAPTER DRIVE MOTOR (CONT)MAX. ACCEL. FROM AVAIL. TORQUE

$$J = \frac{80 \text{ LB}}{32.2} (1 \text{ IN})^2 = 2.48 \text{ LB-FT-SEC}^2$$

$$= 477 \text{ OZ-IN-SEC}^2$$

TORQUE AT ADAPTER $\neq T_d = 11,352 \text{ OZ-IN}$

$$\text{ACCEL. } \alpha = \frac{T}{J} = \frac{11,352}{477} = 23.8 \text{ RAD/SEC}^2 \text{ (1363 } ^\circ\text{/SEC}^2\text{)}$$

MAX MOTOR SPEED @ TRACK RATE = .077°/SEC

$$\omega_m = 100 \times .077^\circ/\text{SEC} = 7.7^\circ/\text{SEC} = .021 \text{ RPS}$$

$$= 1.28 \text{ RPM}$$

$$(\text{MAX ALLOW. MOTOR SPEED} = 210 \text{ RAD/SEC}) = .134 \text{ RAD/SEC}$$

POWER REQUIRED TO TRACK @ .077°/SECNEGLECT BACK EMF, TRACK SPEED $\approx$ STALL SPEED

$$\text{MOTOR CONSTANT @ STALL } K_m = 18.3 \frac{\text{OZ-IN}}{\text{WATT}}$$

$$\text{WATT} = \left(\frac{\text{OZ-IN}}{18.3} \right)^2$$

$$\text{POWER} = \left(\frac{70.9 \text{ OZ-IN}}{18.3} \right)^2 = \underline{15 \text{ WATTS}}$$

AVE. POWER TO ACCEL TO TRACK SPEED (APPROX)

$$P_{\text{AVE}} = \frac{\text{PEAK TORQUE POWER} - \text{TRACK POWER}}{2} + \text{TRACK POWER}$$

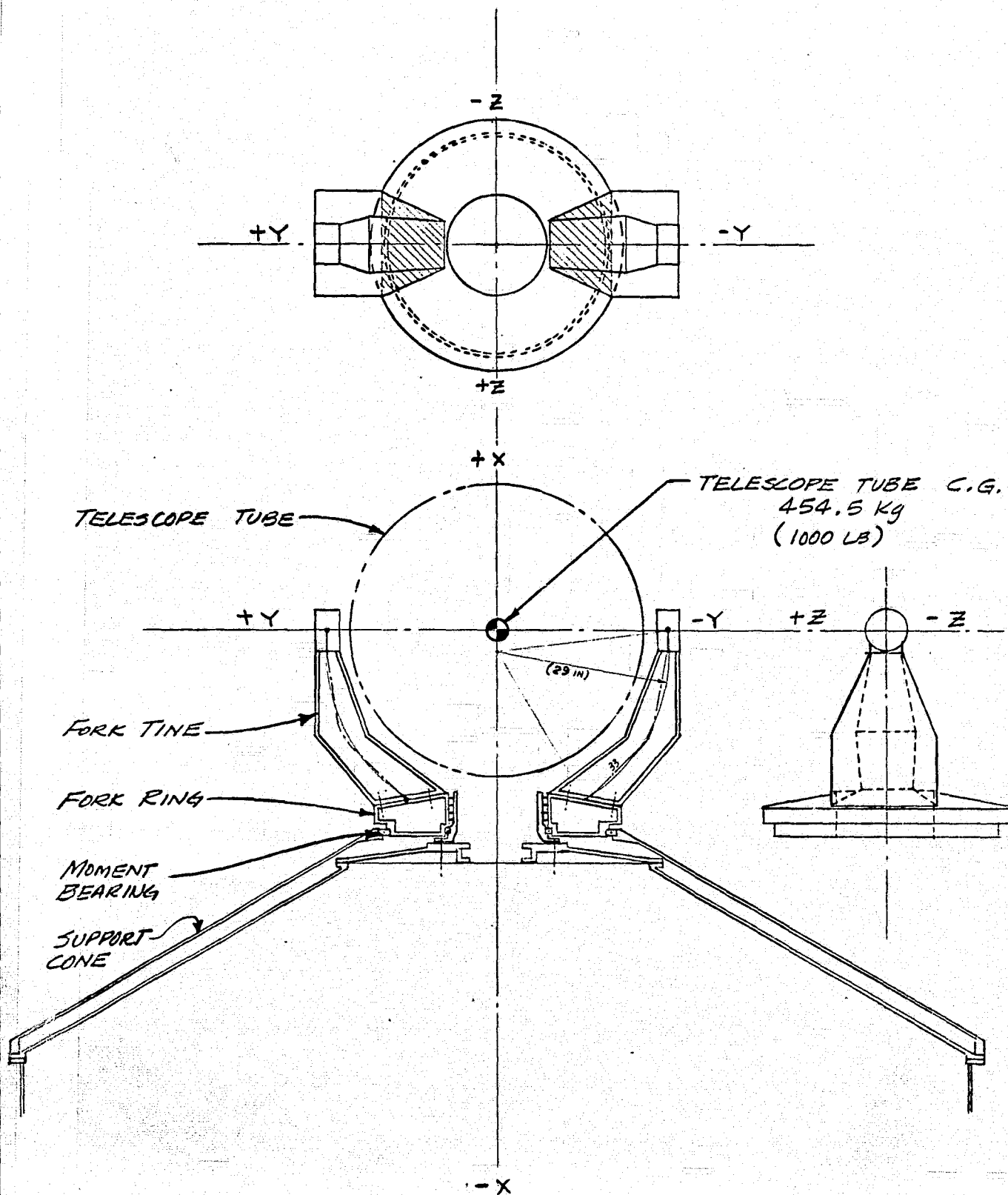
$$= \frac{120 - 15}{2} + 15 = 52.5 + 15 = \underline{67.5 \text{ WATTS}}$$

MIN TIME TO ACCEL. TO TRACK SPEED (.077°/SEC)

$$t = \frac{\omega}{\alpha} = \frac{.077^\circ/\text{SEC}}{1363^\circ/\text{SEC}^2} = .05 \text{ m sec}$$

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DESIGN ANALYSISAEPT FOR SUOTNASA/JSCJOB No. 5906PSHEET OF DATE 2-27-76BY O'Rourke $\frac{1}{2} \times 1'-0"$

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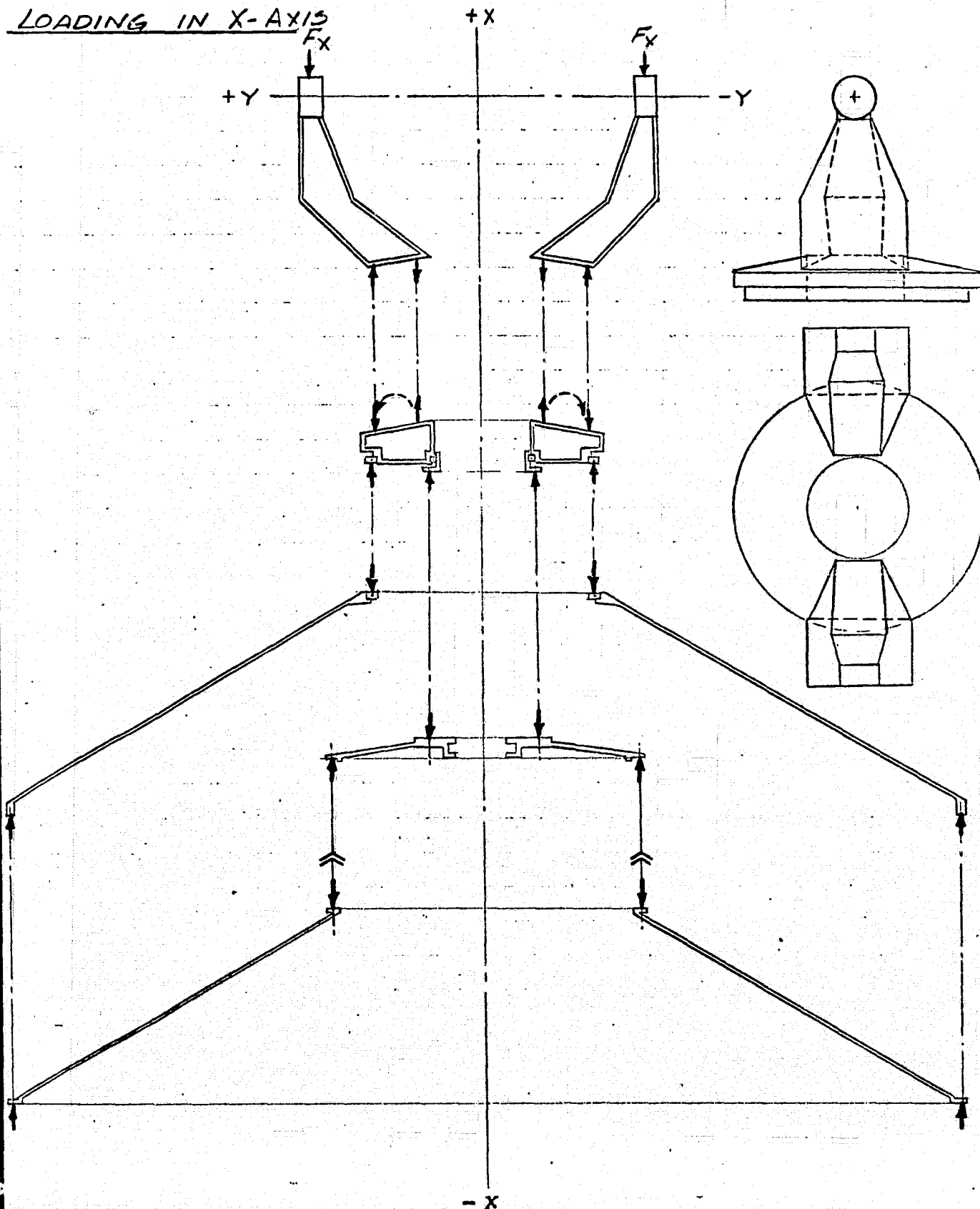
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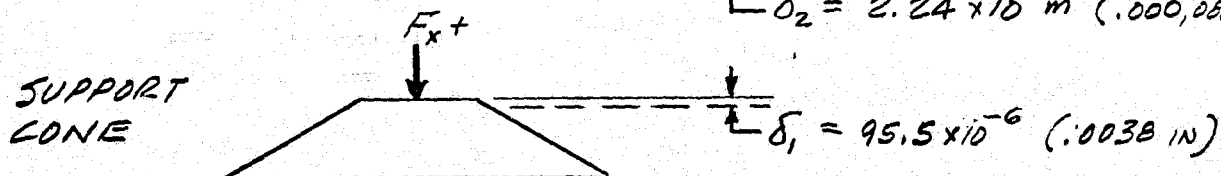
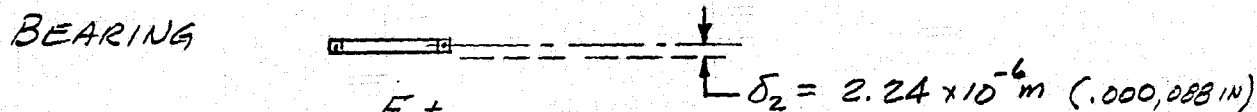
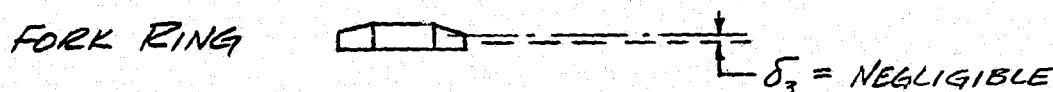
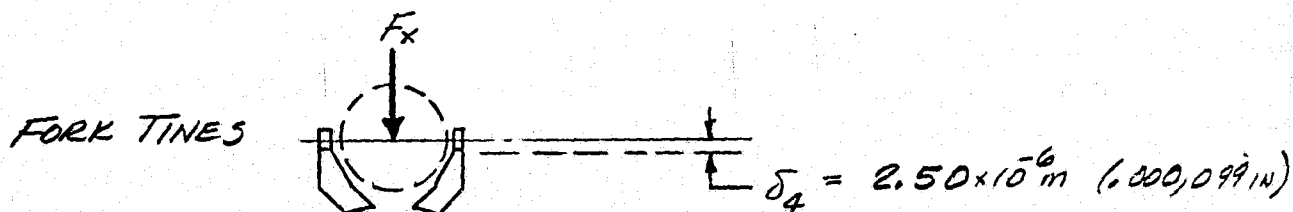
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SHEET OF

DATE 2-27-76

BY D. ROURKE

LOADING IN X-AXIS



$$F_x = 4448 \text{ N } (1000 \text{ LB})$$

$$F_{x+} = 5340 \text{ N } (1200 \text{ LB})$$

TOTAL DEFLECTION AT LOAD

$$\delta_x = \sum \delta_{i,1} = \begin{matrix} \text{CONE} \\ 95\% \end{matrix} \begin{matrix} \text{BEARING} \\ 2.2\% \end{matrix} \begin{matrix} \text{FORK} \\ 0 \end{matrix} \begin{matrix} \text{TINES} \\ 2.8\% \end{matrix} (95.5 + 2.24 + 0 + 2.50) 10^{-6} = 100.24 \times 10^{-6} \text{ m } (.003,9 \text{ in})$$

NATURAL FREQUENCY

$$f_n = \frac{1}{2\pi} \sqrt{\frac{g \sum F \delta_i}{\sum F \delta_i^2}} = \frac{1}{2\pi} \sqrt{\frac{g}{\delta_x}} = \frac{1}{2\pi} \sqrt{\frac{9.8 \text{ m/sec}^2}{1.0024 \times 10^{-4} \text{ m}}} = \underline{50.5 \text{ Hz}}$$

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SHEET OF

DATE 2-27-76

BY O'Rourke

SUPPORT CONE DEFLECTION

LOADING IN X-AXIS

$$F_x = 5340 \text{ N (1200 LB)} = 1g$$

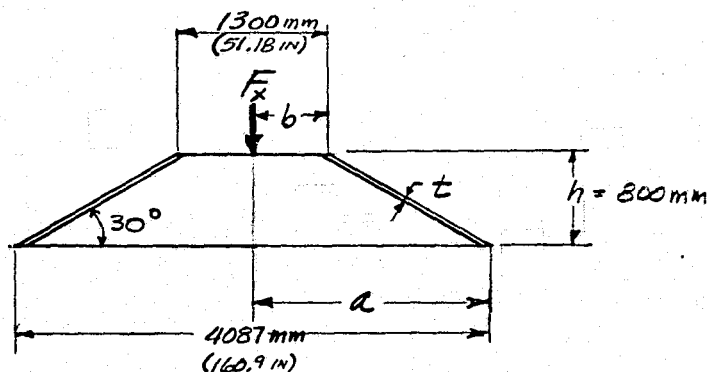
$$a = 2.04 \text{ m (80.45 IN)}$$

$$b = .65 \text{ m (25.6 IN)}$$

$$t = .0035 \text{ m (.138 IN)}$$

$$h = .80 \text{ m (31.5 IN)}$$

$$E = 7.31 \times 10^{10} \text{ N/m}^2$$



CONSIDER CONE AS A BELLEVILLE SPRING WITHOUT BENEFIT OF MOUNTING FLANGES, TOP AND BOTTOM, AND RESTRICTING SUPPORT OF THE SPACE LAB MOUNTING FLANGE (THIS WOULD BE A "WORST CASE" CONDITION).

AXIAL DEFLECTION OF CONE

$$\delta_x = \frac{F_x M a^2 (1-\nu)}{E h^2 t} \quad \text{For } \delta \ll h \quad \nu = \text{POISSON'S RATIO} = .33$$

$$M = \text{CONSTANT} = .79 \quad \text{FOR } a/b = 3.14$$

$$= \frac{5340 (.79) (2.04^2) (1-.33^3)}{7.31 \times 10^{10} (.8^2) (.0035)} = 9.55 \times 10^{-5} \text{ m (.0038 IN)}$$

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DESIGN ANALYSISAFPT FOR SUOTNASA/JSCJOB No. 5906PSHEET OF DATE 2-27-76BY O'RourkeMOMENT BEARING (4-POINT) - LOADING IN THE X-AXISOUTER BEARING - KAYDON 6684-1AXIAL LOAD $F_x = 5340 \text{ N (1200 LB)}$ BEARING AXIAL DEFLECTION (FROM KAYDON FORMULA DEVELOPED FOR THIS BEARING WITH .000,5 IN. PRELOAD)

$$\begin{aligned} \delta_x &= 7.353 \times 10^{-8} \text{ IN/LB (1200 LB)} = \frac{8.82 \times 10^{-5} \text{ IN}}{2.24 \times 10^{-6} \text{ M}} \end{aligned}$$

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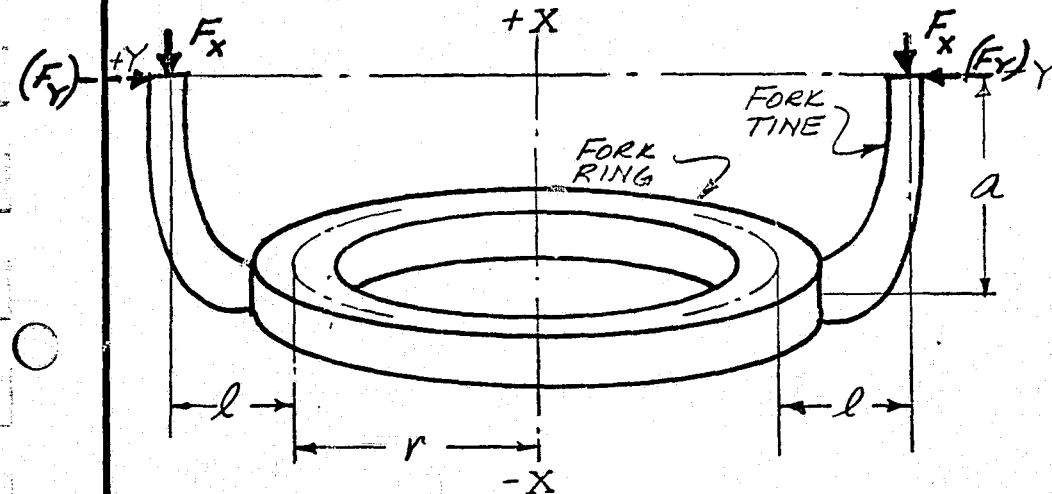
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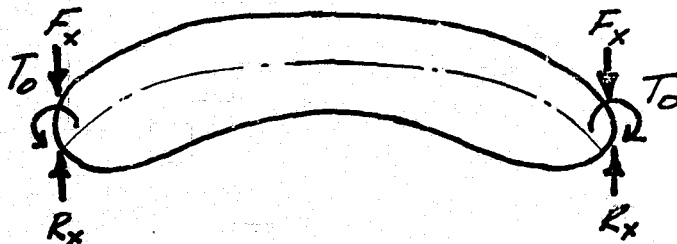
DATE 2-27-76

BY O'ROURKE

FORK RING DEFLECTION - LOADING IN THE X-AXIS



$$\begin{aligned} a &= .762 \text{ m } (30 \text{ in}) \\ K &= 1.217 \times 10^{-4} \text{ m}^4 \\ r &= .3 \text{ m} \\ I_y &= 4.49 \times 10^{-5} \text{ m}^4 \\ E &= 7.31 \times 10^{10} \text{ N/m}^2 \\ G &= 2.76 \times 10^{10} \text{ N/m}^2 \\ \lambda &= \frac{EI}{GK} = .97 \end{aligned}$$



$$\begin{aligned} F_x &= 2225 \text{ N } (500 \text{ LB}) \\ l &= .437 \text{ (17.2 in)} \\ T_o &= F_x l = 972 \text{ N.m } (860 \text{ LB.in}) \end{aligned}$$

RING ROTATION AT FORK TINE (IF TINES WERE FREE TO MOVE Laterally)

$$\beta = \frac{\pi r T_o (1 + \lambda)}{8 EI_y} = \frac{\pi (.3)(972)(1 + .97)}{8 (7.31 \times 10^{10})(4.49 \times 10^{-5})} = \frac{68.73 \times 10^{-6} \text{ RAD } (14^\circ)}{(\text{REF ONLY})}$$

LATERAL TINE MOVEMENT (IF FREE TO MOVE) AT TELES. TUBE

$$\Delta_y = a\beta = .762(68.73 \times 10^{-6}) = 5.24 \times 10^{-5} \text{ m } (.002 \text{ in})$$

RESISTING FORCE REQ'D OF TELES. TUBE AT FORK TINE

$$F_y = \frac{l F_x}{a} = \frac{.437(2225)}{.762} = 1276 \text{ N } (287 \text{ LB})$$

CONCLUSION:

IF TINES ARE RESTRAINED Laterally ($F_y = 1276 \text{ N}$) BY THE TELESCOPE TUBE, THERE WILL BE NO AXIAL DISPLACEMENT OF THE TELESCOPE TUBE FROM FORK RING DEFLECTION

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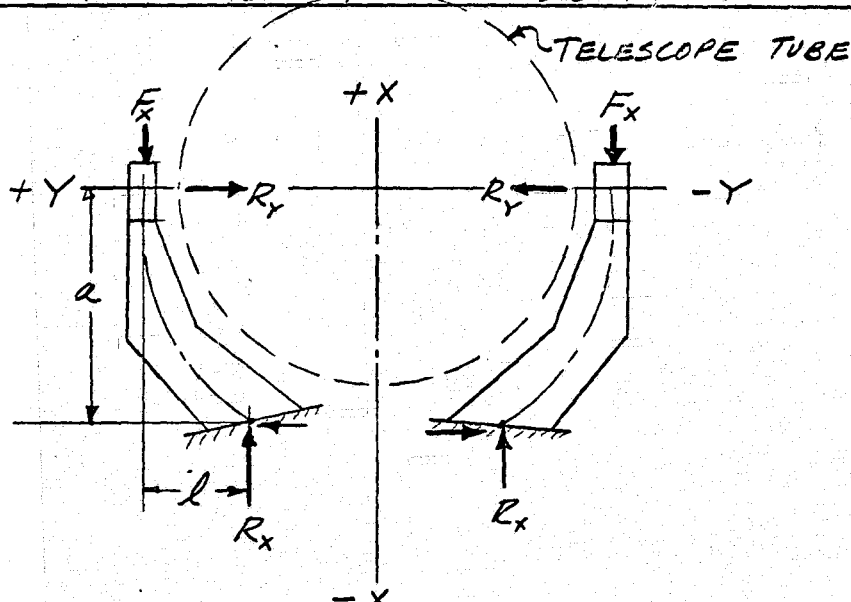
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SHEET OF

DATE 2-27-76

BY O. R. RYKE

FORK DEFLECTION - LOADING IN X-AXIS

$$F_x = 2224 \text{ N (500 LB)}$$

$$l = .356 \text{ m (14 IN)}$$

$$a = .762 \text{ m (30 IN)}$$

TELESCOPE TUBE REACTION

$$R_y = \frac{F_x l}{a} = \frac{2224 (.356)}{.762} = 1276 \text{ N (287 LB)}$$

FORK TINE WILL ACT AS A COLUMN WITH THE TELESCOPE TUBE REACTING TO THE LATERAL FORCE PRODUCED BY THE OFFSET, l .

AXIAL TINE DEFLECTION

$$\delta_x = \frac{F_x a}{A E} = \frac{1276 (.762)}{.0053 (7.31 \times 10^{10})} = \frac{2.5 \times 10^{-6} \text{ m}}{9.88 \times 10^{-5} \text{ IN}}$$

Area $A = 1.195 (.006) (.75) = .0053 \text{ m}^2$

$U = \text{perimeter}$
 $t = .75\% \text{ EFFECTIVE AREA}$

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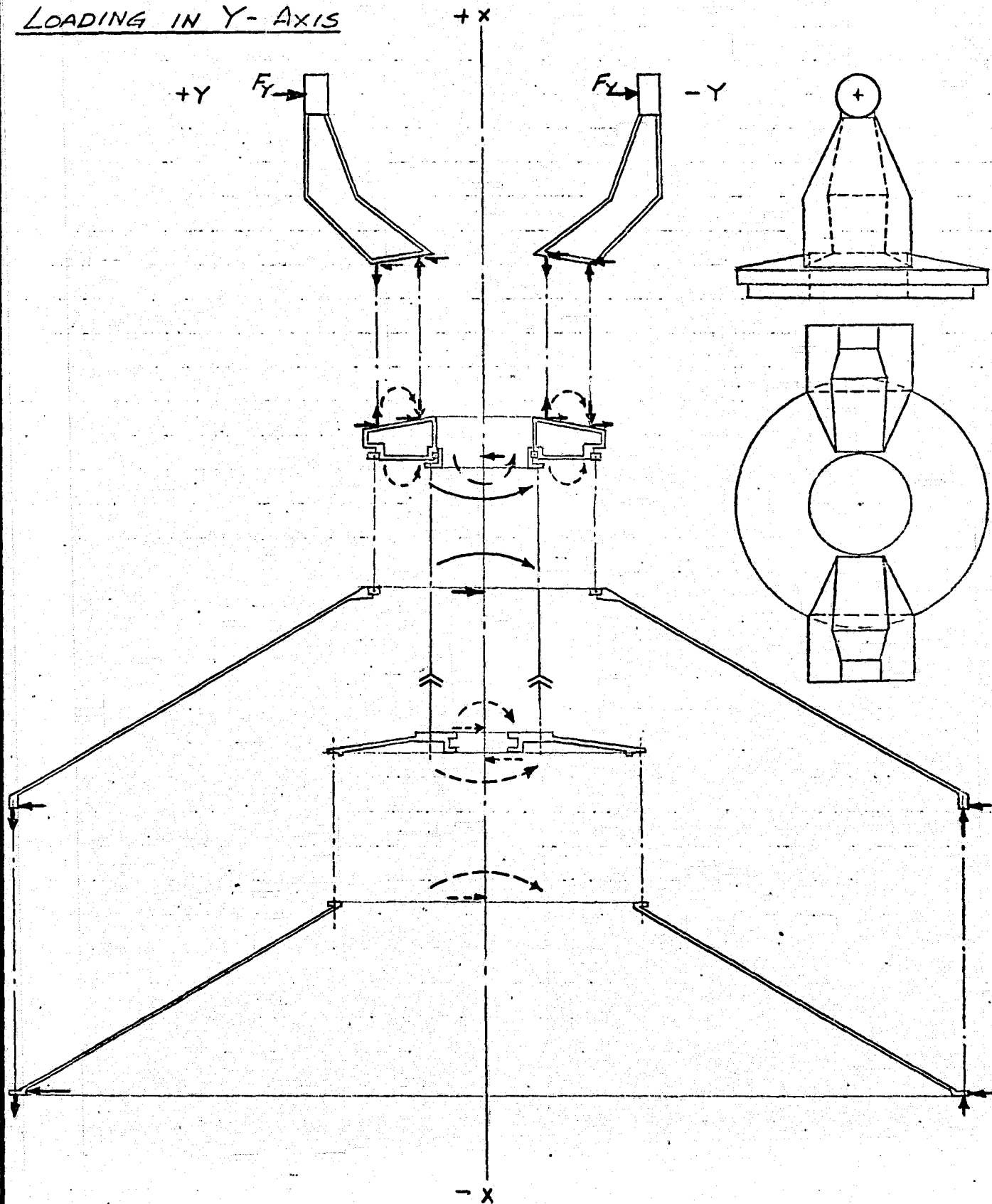
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LOADING IN Y-AXIS



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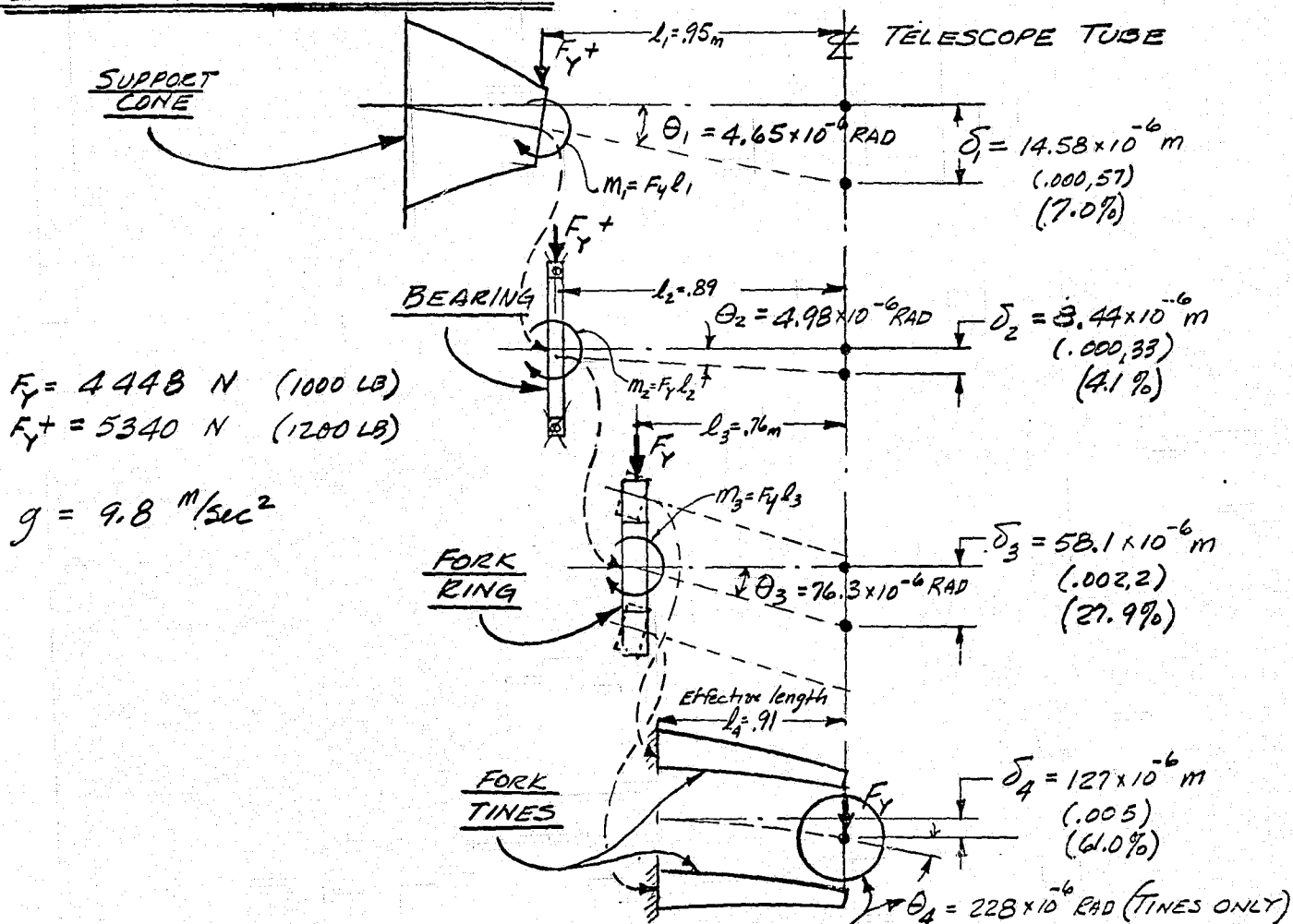
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SHEET OF

DATE 2-27-76

BY O'ROURKE

DEFLECTION & NATURAL FREQUENCY
LOADING IN THE Y-AXISTOTAL DEFLECTION AT LOAD:

COMPONENT	PERCENT	DEFLECTION (m)	PERCENT
CONE	7.0%	14.58	7.0%
BEARING	4.1%	8.44	4.1%
FORK RING	27.9%	58.1	27.9%
FORK TINES	61.0%	127	61.0%

$$\delta_y = \sum \delta = (14.58 + 8.44 + 58.1 + 127) \times 10^{-6} = 208.12 \times 10^{-6} \text{ m} \quad (.0082) \quad (0.208 \text{ mm})$$

ASSUME TELES TUBE DOES NOT ROTATE BECAUSE OF PARALLELOGRAM MOTION

NATURAL FREQUENCY

$$f_n = \frac{1}{2\pi} \sqrt{\frac{g \sum F \delta_y}{\sum F \delta_y^2}} = \frac{1}{2\pi} \sqrt{\frac{g}{\delta_y}} = \frac{1}{2\pi} \sqrt{\frac{9.8 \text{ m/sec}^2}{208.12 \times 10^{-6} \text{ m}}} = 34.5 \text{ Hz}$$

SLOPE

COMPONENT	PERCENT	ANGLE (RAD)	PERCENT
CONE	4.6%	4.65	4.6%
BEARING	19%	4.98	19%
FORK RING	76.4%	76.3	76.4%
FORK TINES		0	

$$\theta_y = \sum \theta = (4.65 + 4.98 + 76.3 + 0) \times 10^{-6} = 85.93 \times 10^{-6} \text{ RAD} \quad (17.7^\circ)$$

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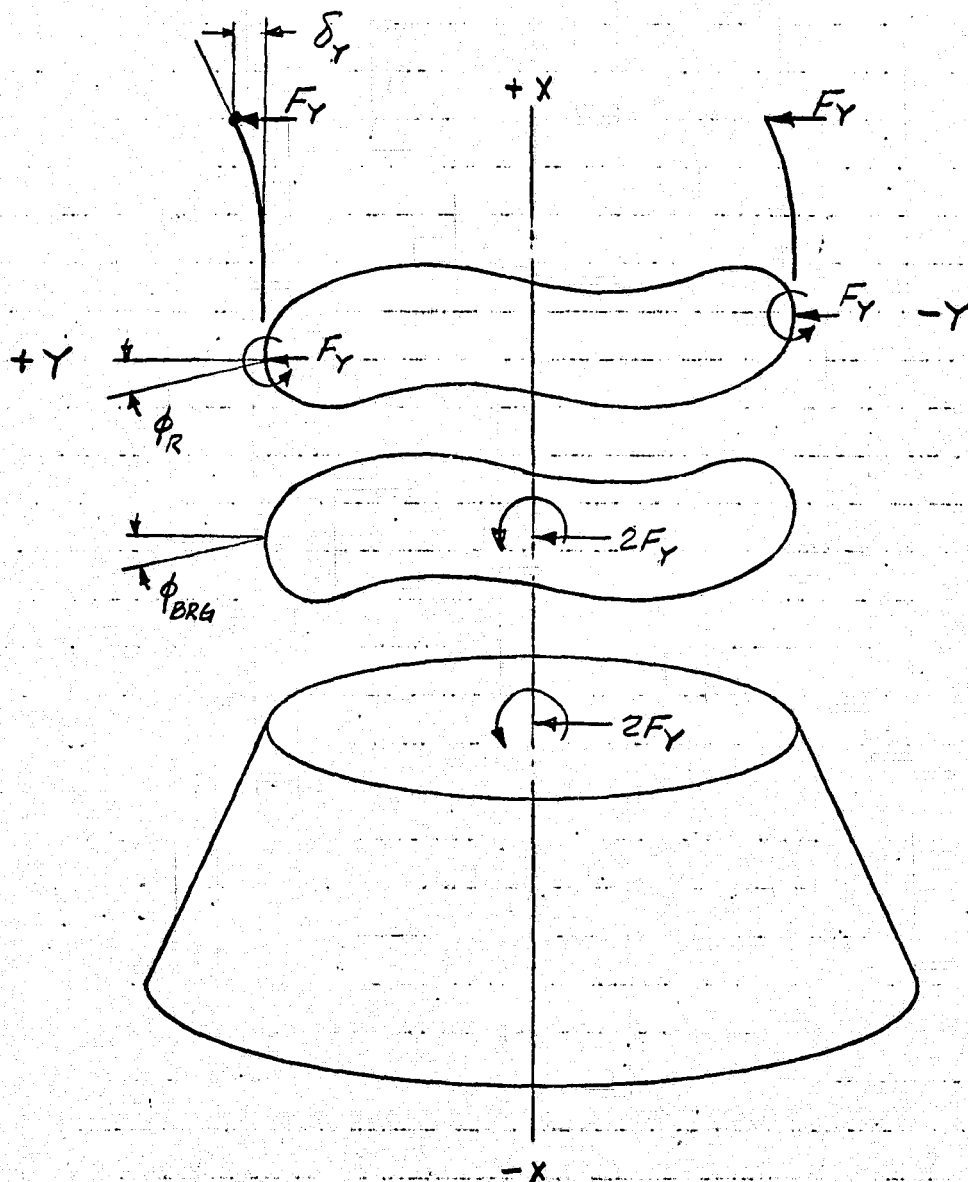
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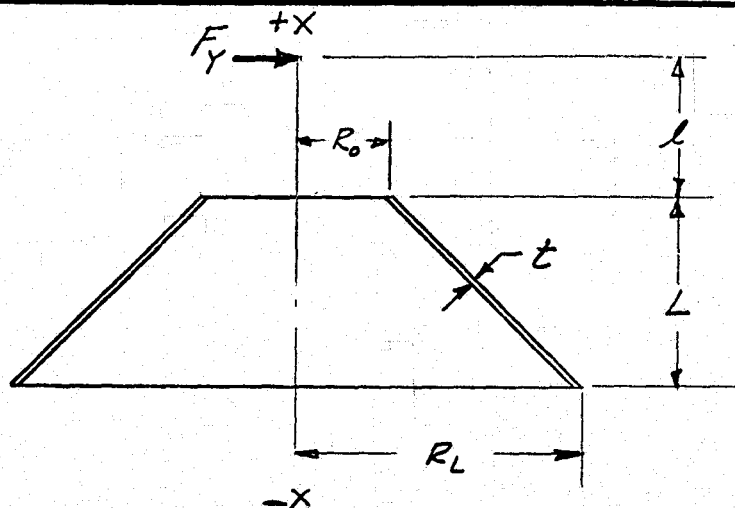
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SHEET OF

DATE 2-27-76

BY O. ROYCE

SUPPORT CONE DEFLECTION
LOADING IN THE Y-AXIS

$$R_o = .65 \text{ m } (25.6 \text{ IN})$$

$$R_L = 2.04 \text{ m } (80.45 \text{ IN})$$

$$L = .80 \text{ m } (31.5 \text{ IN})$$

$$t = .0035 \text{ m } (.138 \text{ IN})$$

$$F_y = 5340 \text{ N } (1200 \text{ LB})$$

$$l = .95 \text{ m } (37.5 \text{ IN})$$

$$M = F_L = 5086 \text{ N}\cdot\text{m}$$

FROM END MOMENT, M

$$\text{SLOPE } \theta_M = \frac{-ML(R_L + R_o)}{2EtC_o R_L^2 R_o^2} = \frac{5086(0.8)(2.04 + .65)}{2(7.31 \times 10^{10})(.0035)(3.14)(2.04^2)(.65)^2}$$

$$= -3.87 \times 10^{-6} \text{ RAD } (.79^\circ)$$

$$\text{DEFLECTION } y_M = \frac{M L^2}{2EtC_o R_o R_L^2} = \frac{5086}{2(7.31 \times 10^{10})(.0035)(3.14)(.65)(2.04)^2}$$

$$= 7.48 \times 10^{-7} \text{ m } (.000,029 \text{ IN})$$

FROM END LOAD, Fy

$$\text{SLOPE } \theta_F = \frac{-F}{2EtC_o R_o} \left(\frac{L}{R_L} \right)^2 = \frac{-5340}{2(7.31 \times 10^{10})(.0035)(3.14)(.65)} \left(\frac{.8}{2.04} \right)^2$$

$$= .785 \times 10^{-6} \text{ RAD}$$

$$\text{DEFLECTION } y_F = \frac{2F}{3EtC_o} \left(\frac{L}{R_L + R_o} \right)^3 \left\{ 1 + \frac{3}{4} \left(1 + \frac{R_o}{R_L} \right)^2 \right\}$$

$$= \frac{2(5340)}{3(7.31 \times 10^{10})(.0035)(3.14)} \left(\frac{.8}{2.04 + .65} \right)^3 \left\{ 1 + \frac{3}{4} \left(1 + \frac{.65}{2.04} \right)^2 \right\}$$

$$= 2.68 \times 10^{-7} \text{ m } (.000,010,6 \text{ IN})$$

(CONT)

PERKIN-ELMER

BOLLER & CHIVENS DIVISION

916 MERIDIAN AVENUE

SOUTH PASADENA, CALIFORNIA 91030

TELEPHONE: (213) 682-3391

DESIGN ANALYSISAEPT FOR SUOTNASA / JSCJOB No. 5906PSHEET OF DATE 2-27-76BY O'ROURKESUPPORT CONE DEFLECTION (CONT)
(Y-AXIS LOADING)

TELESCOPE TUBE ROTATION FROM CONE DEFLECTION

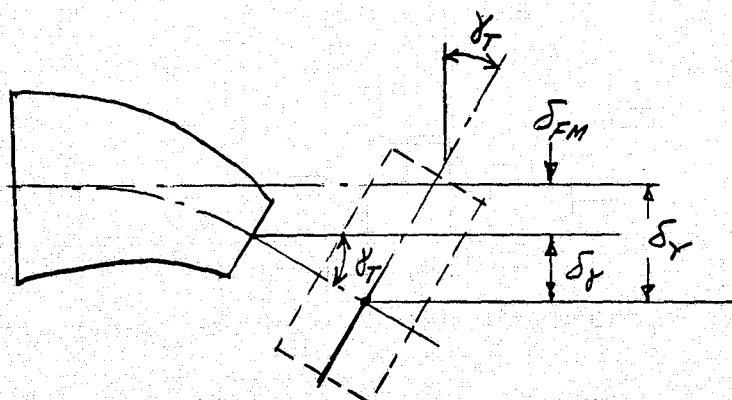
$$\gamma_T = \gamma_m + \gamma_F = 3.87 \times 10^{-6} + .78 \times 10^{-6} = \underline{4.65 \times 10^{-6} \text{ RAD.}}$$

TELESCOPE TUBE DEFLECTION FROM CONE DEFLEC + ROTATION

$$\delta_y = \gamma_T L = 4.65 \times 10^{-6} (.95) = 4.42 \times 10^{-6} \text{ m}$$

$$\delta_{FM} = y_m + y_F = 7.48 \times 10^{-7} + 2.68 \times 10^{-7} = 10.16 \times 10^{-7} \text{ m } (.000,040 \text{ IN})$$

$$\delta_Y = \delta_y + \delta_{FM} = \underline{14.58 \times 10^{-6} \text{ m } (.000,57 \text{ IN})}$$



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DESIGN ANALYSISAFPT FOR SUOTNASA/JSCJOB No. 5906PSHEET OF DATE 2-27-76BY O'RourkeMOMENT BEARING (4-PT) - LOADING IN THE Y-AXISOUTER BEARINGMOMENT LOADINGREPRODUCIBILITY OF THE
ORIGINAL PAGE IS POOR

$$\begin{aligned}
 F_Y &= 5340 \text{ N (1200 LB)} \\
 l &= .89 \text{ m (35 IN.)} \\
 M &= Fl = 4747 \text{ N}\cdot\text{m (42,000 LB}\cdot\text{IN.)}
 \end{aligned}$$

BEARING DEFLECTION FROM MOMENT LOADING:

$$\theta_m = M \times C_m$$

WHERE $C_m = 1.187 \times 10^{-10} \frac{\text{RAD}}{\text{IN}\cdot\text{LB}}$ FROM
GRAPH DEVELOPED BY KAYDON BRG Co
FOR .0005 IN. PRELOADED 4-PT BEARING

$$\theta_m = 42,000 (1.187 \times 10^{-10} \frac{\text{RAD}}{\text{IN}\cdot\text{LB}}) = 4.98 \times 10^{-6} \text{ RAD (1}^\circ)$$

BEARING DEFLECTION FROM RADIAL LOADING

$$\delta_R = F_Y C_R$$

$$C_R = 1.316 \times 10^{-7} \frac{\text{IN}}{\text{LB}}$$

$$= 1200 \text{ LB} \times 1.316 \times 10^{-7} \frac{\text{IN}}{\text{LB}} = .000,158 \text{ IN (4.01} \times 10^{-6} \text{ m)}$$

DEFLECTION AT TELESCOPE TUBE FROM MOMENT LOAD:

$$\delta_\theta = \theta_m \times l = 4.98 \times 10^{-6} \text{ RAD} \times (.89) = 4.43 \times 10^{-6} \text{ m (.000,17 IN)}$$

TOTAL DEFLECTION AT TELESCOPE TUBE FROM MOM. & RADIAL LOADS

$$\delta_Y = \delta_R + \delta_\theta = 4.01 \times 10^{-6} \text{ m} + 4.43 \times 10^{-6} \text{ m} = \underline{8.44 \times 10^{-6} \text{ m}} \\ (.000,33 \text{ IN})$$

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JOB No. 5906P

SHEET OF

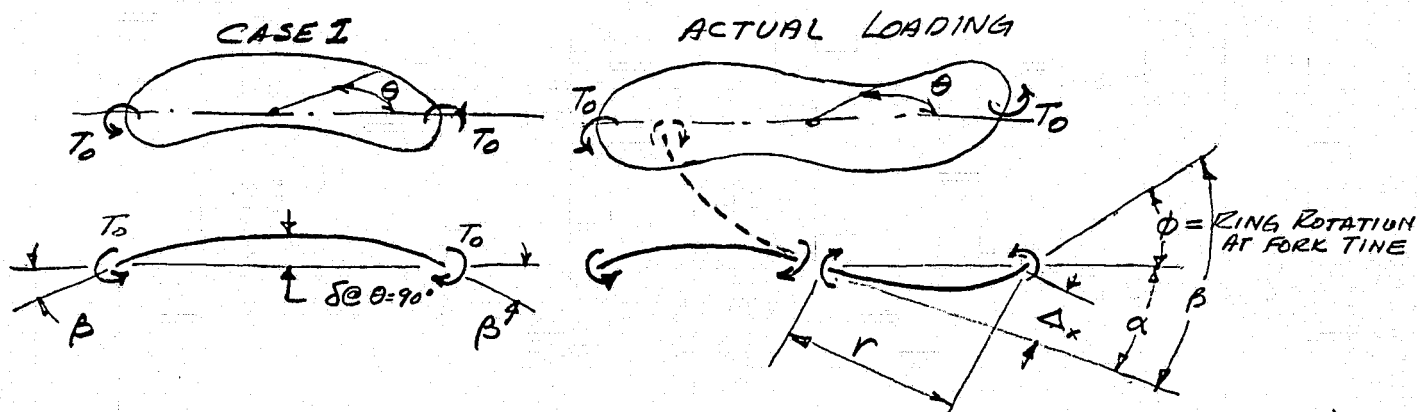
DATE 2-27-76

BY D'ROURKE

FORK RING DEFLECTION Y-AXIS LOADING

CONSIDER THE FORK RING UNDER EQUAL AND OPPOSITE TWISTING MOMENTS FROM LOADING OF THE FORK TINES IN THE Y DIRECTION

CASE 1 WILL BE USED TO DETERMINE THE ROTATION ANGLE



CASE 1 HAS ZERO SLOPE AT THE MID POSITION ($\theta = 90^\circ$)
BY METHOD OF SUPERPOSITION, ONE HALF THE RING CAN BE
INVERTED AND ALIGNED WITH THE END POINTS AND MID-POSITION
ON THE RING CENTER LINE PLANE

$$K = 1.217 \times 10^{-4} \text{ m}^4$$

$$r = .3 \text{ m}$$

$$I_y = 4.49 \times 10^{-5} \text{ m}^4$$

$$E = 7.31 \times 10^{10} \text{ N/m}^2$$

$$G = 2.76 \times 10^{10} \text{ N/m}^2$$

$$\lambda = \frac{E I_y}{G K} = .97$$

$$F_y = 2225 \text{ N (500 LB)}$$

$$l_y = .762 \text{ m (30 IN)}$$

$$T_{0y} = F_y l_y = 1695.5 \text{ N} \cdot \text{m}$$

(CONT)

PERKIN-ELMER

BOLLER & CHIVENS DIVISION

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DESIGN ANALYSISAFT FOR SUOTNASA / JSCJOB No. 5906PSHEET OF DATE 2-27-76BY O'ROURKE

CONSERVATIVE APPROACH:

RING CONSIDERED AS A FREE STANDING BODY WITHOUT BENEFIT OF THE INNER & OUTER BEARINGS GIVING ADDED STIFFNESS THRU THE SUPPORT CONES.

FORK RING DEFLECTION
(CONT)

$$\Delta_Y = \frac{r^2 T_{OY} (1+\lambda) (\pi-2)}{8EI} = \frac{.3^2 (1695.5) (1.97) (1.1416)}{8(7.31 \times 10^{10}) (4.49 \times 10^{-5})}$$

$$= 13.05 \times 10^{-6} \text{ m } (.00051 \text{ IN})$$

$$\alpha_Y = \frac{\delta_Y}{r} = \frac{13.05 \times 10^{-6}}{0.3} = 4.35 \times 10^{-5} \text{ RAD}$$

$$\beta_Y = \frac{\pi r T_{OY} (1+\lambda)}{8EI} = \frac{\pi (.3) (1694.5) (1.97)}{8(7.31 \times 10^{10}) (4.49 \times 10^{-5})} = 11.98 \times 10^{-5} \text{ RAD}$$

RING ROTATION @ FORK TINE:

$$\phi_Y = \beta - \alpha = \underline{7.63 \times 10^{-5} \text{ RAD}} \quad (15.7^\circ)$$

TELESCOPE TUBE DEFLECTION AT END OF FORK TINE

$$\delta_Y = \phi_Y \cdot L_Y = (7.63 \times 10^{-5}) (.762) = \underline{5.81 \times 10^{-5} \text{ m}} \quad (.0022 \text{ IN})$$

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DESIGN ANALYSIS

AEPT FOR SUOT

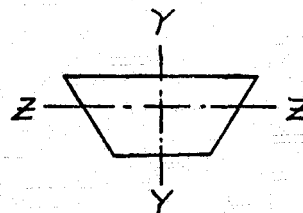
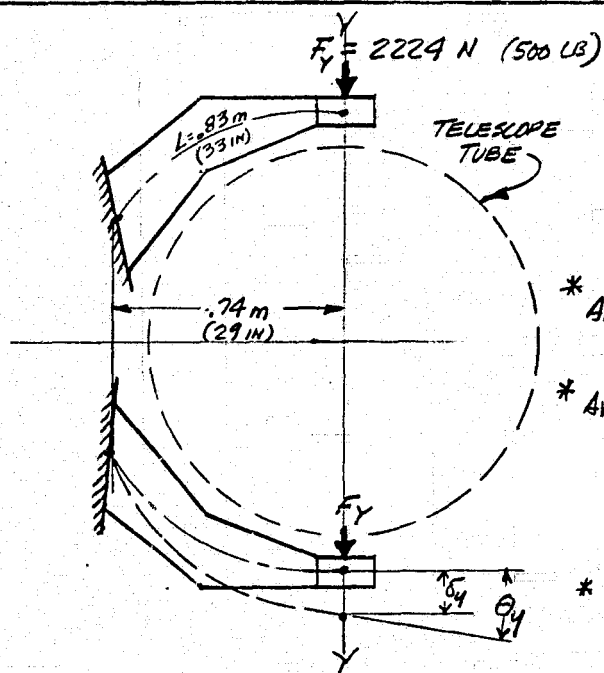
NASA/JSC

JOB No. 59060

SHEET OF

DATE 2-27-76

BY O'Rourke

FORK DEFLECTION - LOADING IN Y-AXIS

$$* \text{AVE } I_{Y-Y} = 9.3 \times 10^{-5} \text{ m}^4 (223 \text{ in}^4)$$

$$* \text{AVE } I_{Z-Z} = 4.6 \times 10^{-5} \text{ m}^4 (110 \text{ in}^4)$$

$$* K = 1.53 \times 10^{-4} \text{ m}^4 (367 \text{ in}^4)$$

* SEE SHTS FOR FORK TINE PROPERTIES

CONSIDER TINE A SIMPLE CANTILEVER WITH EFFECTIVE LENGTH OF CURVED ARC, L .

DEFLECTION

$$\delta_y = \frac{F_y L^3}{3 E I_z} = \frac{2224 (.83)^3}{3 (7.31 \times 10^{10}) (4.6 \times 10^{-5})} = \underline{1.27 \times 10^{-4} \text{ m}} (1.005 \text{ in})$$

SLOPE

$$\theta_y = \frac{F_y L^2}{2 E I_z} = \frac{2224 (.83)^2}{2 (7.31 \times 10^{10}) (4.6 \times 10^{-5})} = \underline{228 \times 10^{-6} \text{ RAD}} (47^\circ)$$

NOTE: TINES WILL APPROXIMATELY ROTATE AS A PARALLELOGRAM SYSTEM AND THUS PRODUCE NO ROTATION OF THE TELESCOPE TUBE

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TELEPHONE: (213) 682-3391

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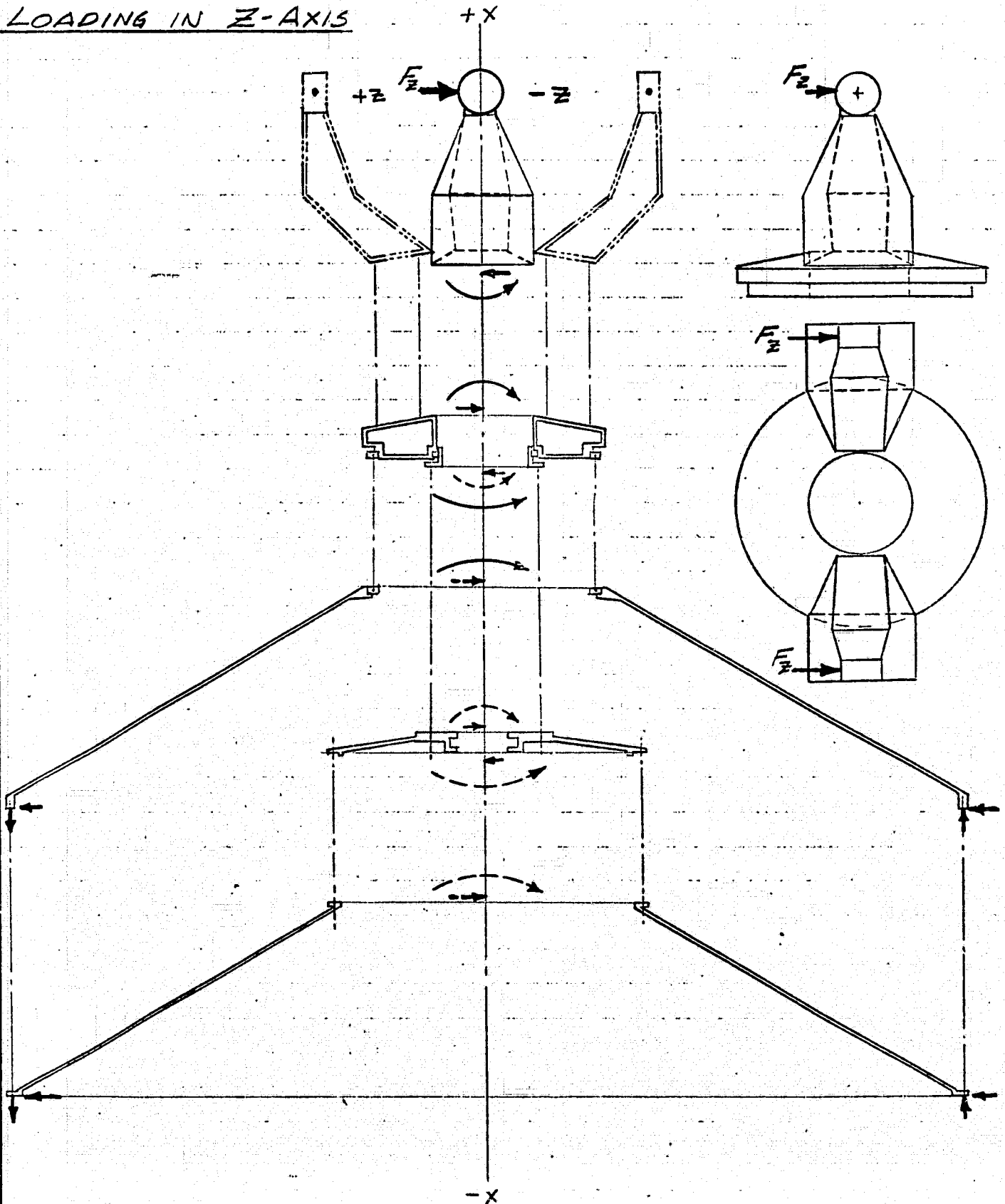
JOB No. 5906P

SHEET OF

DATE 2-27-76

BY O'Rourke

LOADING IN Z-AXIS



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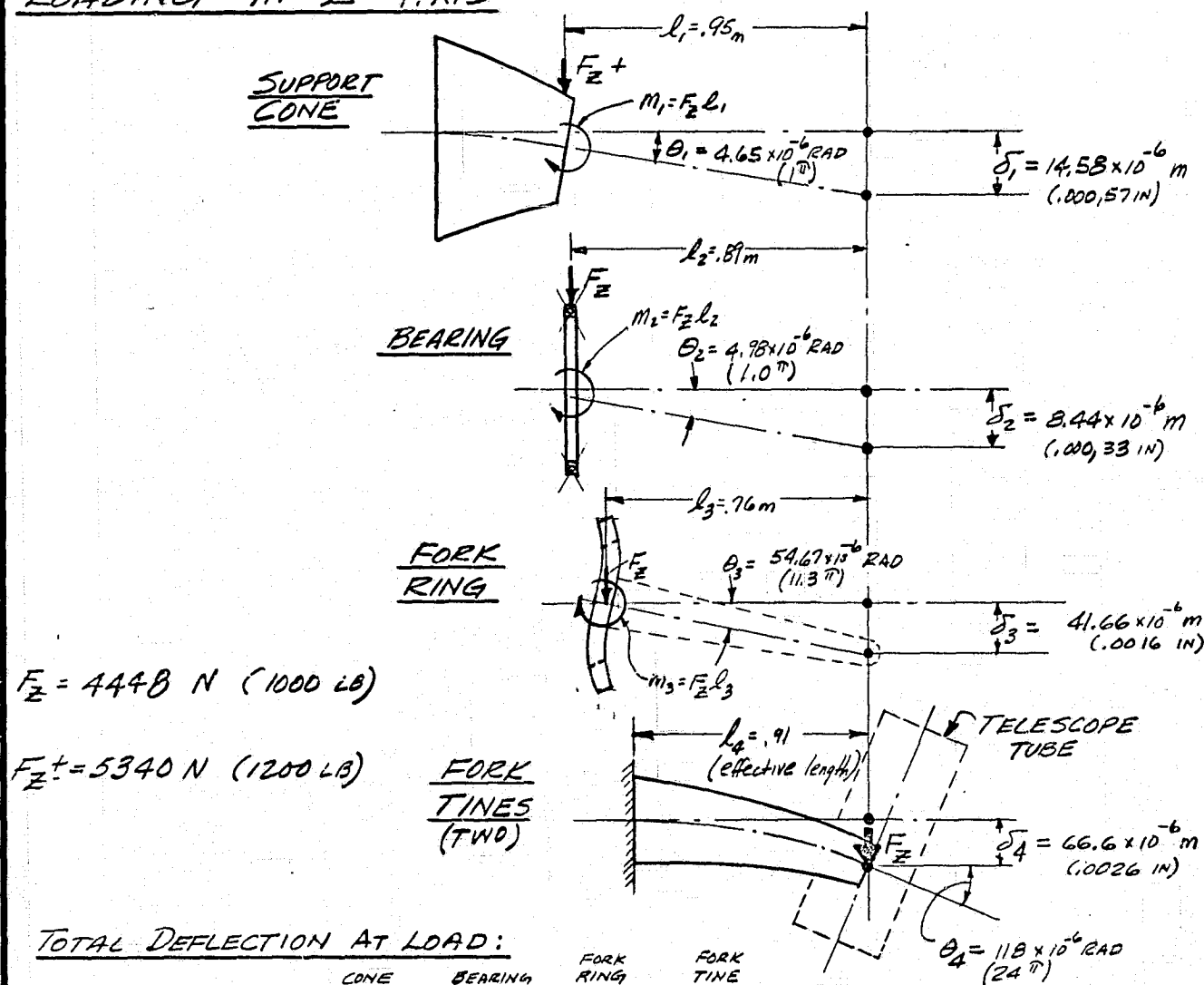
JOB NO. 59068

SHEET OF

DATE 2-27-76

BY O'ROURKE

LOADING IN Z-AXIS



TOTAL DEFLECTION AT LOAD:

COMPONENT	PERCENT	DEFLECTION (m)	DEFLECTION (IN)
CONE	11.1%	14.58	0.00057
BEARING	6.4%	8.44	0.00033
FORK RING	31.7%	41.66	0.0016
FORK TINE	50.8%	66.6	0.0026
TOTAL		131.28	0.0052

$$\delta_z = \sum \delta_z = (14.58 + 8.44 + 41.66 + 66.6) 10^{-6} = 131.28 \times 10^{-6}\text{ m} \text{ (.0052 IN)}$$

NATURAL FREQUENCY

$$f_{nz} = \frac{1}{2\pi} \sqrt{\frac{9 \sum F \delta_z}{\sum F \delta_z^2}} = \frac{1}{2\pi} \sqrt{\frac{9}{\delta_z}} = \frac{1}{2\pi} \sqrt{\frac{9.8 \text{ m/sec}^2}{1.313 \times 10^{-4} \text{ m}}} = 43.5 \text{ Hz}$$

SLOPE

COMPONENT	PERCENT	ANGLE (RAD)	ANGLE (DEG)
CONE	2.6%	4.65	1.0
BEARING	2.7%	4.98	1.0
FORK RING	30.0%	54.67	11.3
FORK TINE	64.7%	118	24
TOTAL		182.30	37.6

$$\theta_z = \sum \theta_z = (4.65 + 4.98 + 54.67 + 118) 10^{-6} = 182.30 \times 10^{-6}\text{ RAD} \text{ (37.6}^\circ\text{)}$$

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DESIGN ANALYSIS

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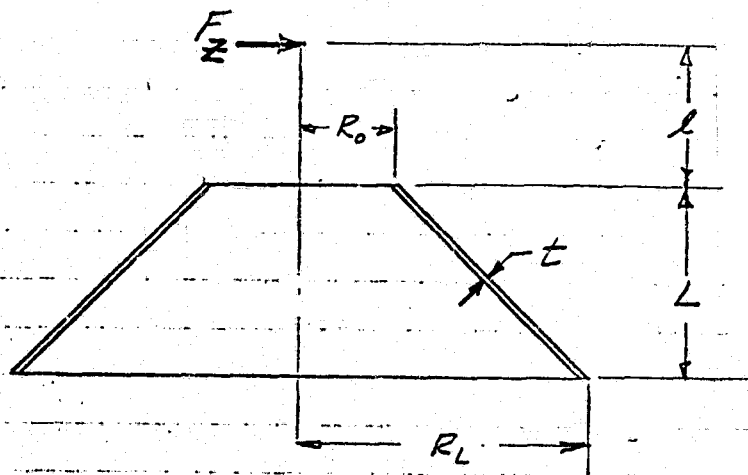
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SHEET OF

DATE 2-27-76

BY O'Rourke

SUPPORT CONE DEFLECTION
LOADING IN THE Z-AXIS

$$R_0 = .65 \text{ m (25.6 in)}$$

$$R_L = 2.04 \text{ m (80.45 in)}$$

$$L = .80 \text{ m (31.5 in)}$$

$$t = .0035 \text{ m (.138 in)}$$

$$F_z = 5340 \text{ N (1200 LB)}$$

$$L = .95 \text{ m (37.5 in)}$$

$$M = F_L = 5086 \text{ N}\cdot\text{m}$$

FROM END MOMENT, M

$$\begin{aligned} \text{SLOPE } \theta_H &= \frac{-ML(R_L + R_0)}{2EtC_0R_L^2R_0^2} = \frac{5086(0.8)(2.04 + .65)}{2(7.31 \times 10^{10})(.0035)(3.14)(2.04^2)(.65)^2} \\ &= -3.87 \times 10^{-6} \text{ RAD } (.79^\circ) \end{aligned}$$

$$\begin{aligned} \text{DEFLECTION } y_H &= \frac{ML^2}{2EtC_0R_0R_L^2} = \frac{5086}{2(7.31 \times 10^{10})(.0035)(3.14)(.65)\left(\frac{.8}{2.04}\right)^2} \\ &= 7.48 \times 10^{-7} \text{ m (.000,029 in)} \end{aligned}$$

FROM END LOAD, F

$$\begin{aligned} \text{SLOPE } \theta_F &= \frac{-F}{2EtC_0R_0} \left(\frac{L}{R_L}\right)^2 = \frac{-5340}{2(7.31 \times 10^{10})(.0035)(3.14)(.65)\left(\frac{.8}{2.04}\right)^2} \\ &= .785 \times 10^{-6} \text{ RAD} \end{aligned}$$

$$\begin{aligned} \text{DEFLECTION } y_F &= \frac{2F}{3EtC_0} \left(\frac{L}{R_L + R_0}\right)^3 \left\{ 1 + \frac{3}{4} \left(1 + \frac{R_0}{R_L}\right)^2 \right\} \\ &= \frac{2(5340)}{3(7.31 \times 10^{10})(.0035)(3.14)\left(\frac{.8}{2.04 + .65}\right)^3} \left\{ 1 + \frac{3}{4} \left(1 + \frac{.65}{2.04}\right)^2 \right\} \\ &= 2.68 \times 10^{-7} \text{ m (.000,010,6 in)} \end{aligned}$$

(CONT)

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TELEPHONE: (213) 682-3391

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SHEET OF

DATE 2-27-76

BY O'ROURKE

SUPPORT CONE DEFLECTION (CONT)
(Z-AXIS LOADING)

TELESCOPE TUBE ROTATION FROM CONE DEFLECTION

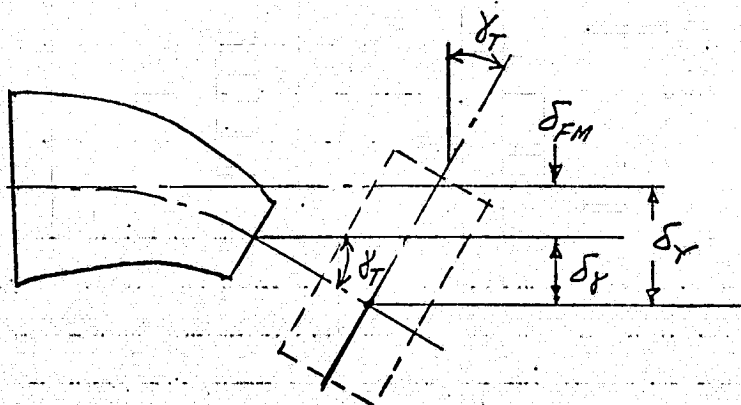
$$\gamma_T = \gamma_M + \gamma_F = 3.87 \times 10^{-6} + .78 \times 10^{-6} = \underline{4.65 \times 10^{-6} \text{ RAD.}}$$

TELESCOPE TUBE DEFLECTION FROM CONE DEFLEC + ROTATION

$$\delta_y = \gamma_T l = 4.65 \times 10^{-6} (.95) = 4.42 \times 10^{-6} \text{ m}$$

$$\delta_{FM} = y_M + y_F = 7.48 \times 10^{-7} + 2.68 \times 10^{-7} = 10.16 \times 10^{-7} \text{ m } (.000,040 \text{ IN})$$

$$\delta_z = \delta_y + \delta_{FM} = \underline{14.58 \times 10^{-6} \text{ m } (.000,57 \text{ IN})}$$



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TELEPHONE: (213) 682-3391

DESIGN ANALYSISAEPT FOR SUOTNASA J-15CJOB NO. 5906PSHEET OF DATE 2-27-76BY O'BUCKEMOMENT BEARING (4-PT) - LOADING IN THE Z-AXISOUTER BEARINGMOMENT LOADING

$$F_z = 5340 \text{ N (1200 LB)}$$

$$l = .89 \text{ m (35 IN)}$$

$$M = F_z l = 5340 (.89) = 4747 \text{ N.m (42,000 LB-IN)}$$

BEARING DEFLECTION FROM MOMENT LOADING:

$$\theta_m = M \times C_m$$

WHERE $C_m = 1.187 \times 10^{-10} \frac{\text{RAD}}{\text{IN-LB}}$ FROM
GRAPH DEVELOPED BY KAYDON BRG. G.
FOR .000,5 IN. PRELOADED 4-PT BRG.

$$\theta_m = 42,000 (1.187 \times 10^{-10}) = 4.98 \times 10^{-6} \text{ Rad. (1"})$$

BEARING DEFLECTION FROM RADIAL LOADING

$$\delta_R = F_z C_R$$

WHERE $C_R = 1.316 \times 10^{-7} \text{ IN/LB}$

$$= 1200 \times 1.316 \times 10^{-7} = .000,158 \text{ IN. (4.01} \times 10^{-6} \text{ m)}$$

DEFLECTION AT TELES. TUBE FROM MOMENT LOAD:

$$\delta_\theta = \theta_m l = 4.98 \times 10^{-6} (.89) = 4.43 \times 10^{-6} \text{ m (.000,17 IN.)}$$

TOTAL DEFLECTION AT TELES. TUBE FROM MOM. & RADIAL LOADS:

$$\delta_z = \delta_R + \delta_\theta = 4.01 \times 10^{-6} + 4.43 \times 10^{-6} = \underline{8.44 \times 10^{-6} \text{ m}} \\ \text{(1.000,33 IN.)}$$

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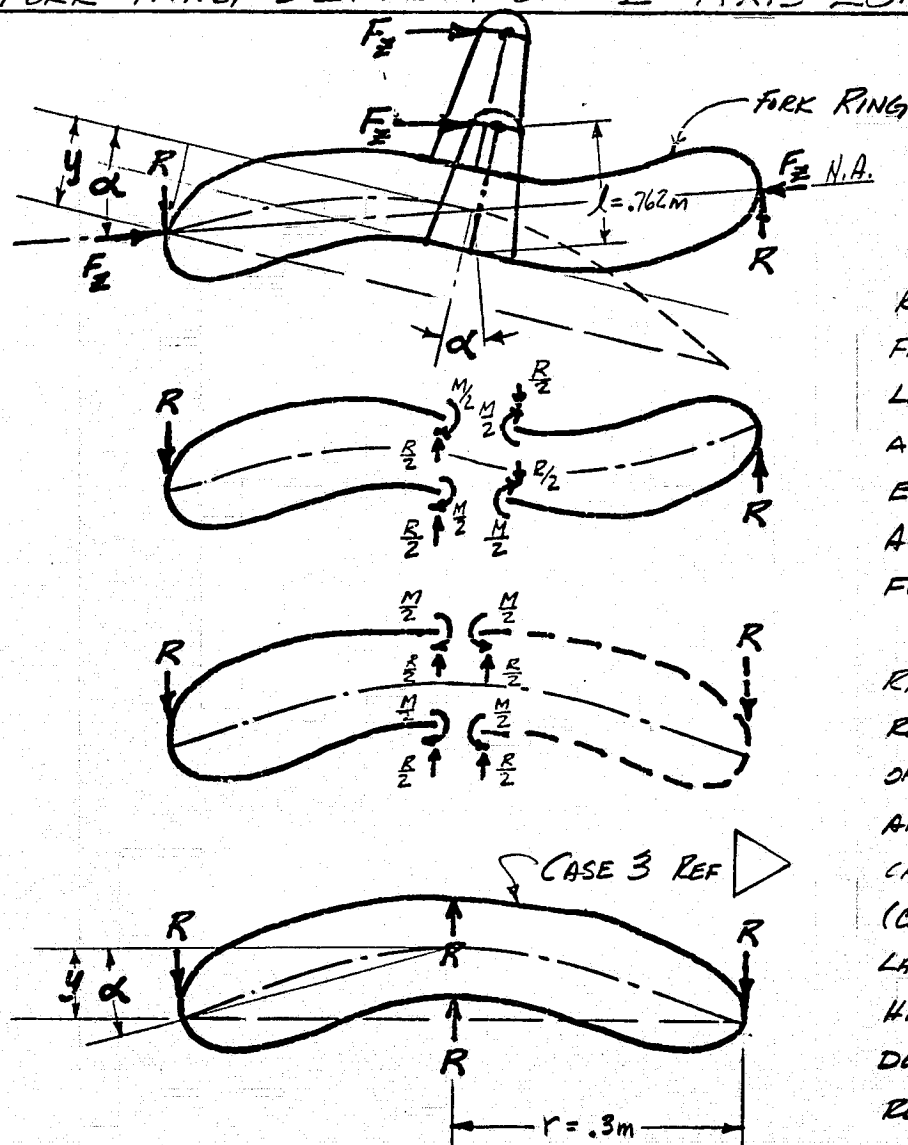
JOB No. 5906P

SHEET OF

DATE 2-27-76

BY D'ROURKE

FORK RING DEFLECTION Z-AXIS LOADING

 α = FORK TINE ROTATION

RING IS CONSIDERED TO BE FREE STANDING WITH MOMENT LOADS AT THE MID-SECTION AND SIMPLE SUPPORTS AT THE EXTREME SECTIONS. (RING IS ACTUALLY SUPPORTED AROUND ITS FULL DIAMETER)

BY METHOD OF SUPERPOSITION, RING IS TAKEN APART AND ROTATED TO CONFORM TO CASE 3 OF REF 5. THE RING DEFLEC. AND THUS THE TINE ROTATION CAN THEN BE DETERMINED. (CONSERVATIVE ANALYSIS). THE LATERAL LOAD AND REACTION HAVE BEEN NEGLECTED AS THEY DO NOT CONTRIBUTE TO TINE ROTATION.

$$F_z = 2225 \text{ N (500 LB)}$$

$$l = .762 \text{ m (30 IN)}$$

$$M = 2225(.762) = 1695.5 \text{ N}\cdot\text{m}$$

$$R = \frac{2M}{2r} = \frac{1695.5}{.3} = 5652 \text{ N}$$

$$K = \text{TORSIONAL SHAPE FACTOR} = 1.217 \times 10^{-4} \text{ m}^4$$

$$I_y = \text{MOMENT OF INERTIA ABOUT NEUTRAL AXIS} = 4.49 \times 10^{-5} \text{ m}^4$$

$$E = \text{MODULUS OF ELASTICITY} = 7.31 \times 10^{10} \text{ N/m}^2$$

$$G = \text{MODULUS OF RIGIDITY} = 2.76 \times 10^{10} \text{ N/m}^2$$

$$\lambda = \text{RATIO OF FLEXURAL TO TORSIONAL RIGIDITY} = \frac{EI}{GK} = .97$$

(Cont)

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TELEPHONE: (213) 682-3391

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JOB No. 5906P

SHEET OF

DATE 2-27-76

BY O. ROVERKE

FORK RING DEFLECTION - Z-AXIS LOADING (CONT)SOLVE FOR DEFLECTION y AT REACTION POINTS

$$y = \frac{Rr^3}{8EI} (2.28 + .566\lambda) = \frac{5652 (.3^3)}{8(7.31 \times 10^{10})(4.49 \times 10^{-5})} \left[2.28 + .566(.97) \right]^{2.82}$$

$$= 1.64 \times 10^{-5} \text{ m } (.000,65 \text{ IN})$$

$$\alpha = \frac{y}{r} = \frac{1.64 \times 10^{-5}}{.3} = 54.67 \times 10^{-6} \text{ RAD}$$

$$\beta = \frac{Er^2}{8EI} (1+\lambda)(2-\pi) = \frac{5652 (.3^2)}{8(7.31 \times 10^{10})(4.49 \times 10^{-5})} (1+.97)(-1.14)^{-2.249}$$

$$= 43.57 \times 10^{-6} \text{ RAD (REF ONLY) (TWIST AT REACTION POINT)}$$

RING ROTATION AT FORK TINE:

$$\theta_z = \alpha = \underline{\underline{54.67 \times 10^{-6} \text{ RAD}}} \quad (11.27^\circ)$$

TELESCOPE TUBE DEFLECTION AT END OF FORK TINE

$$\delta_z = \theta_z l = 54.67 \times 10^{-6} (.762) = \underline{\underline{41.66 \times 10^{-6} \text{ m}}} \quad (.0016 \text{ IN})$$

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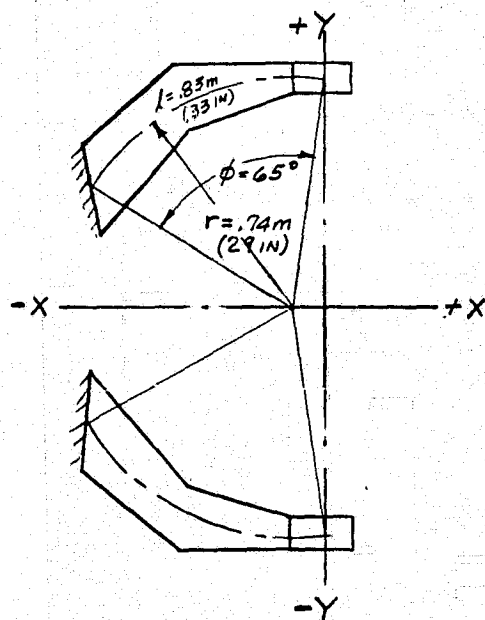
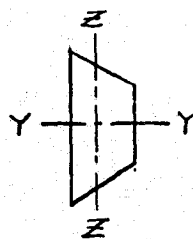
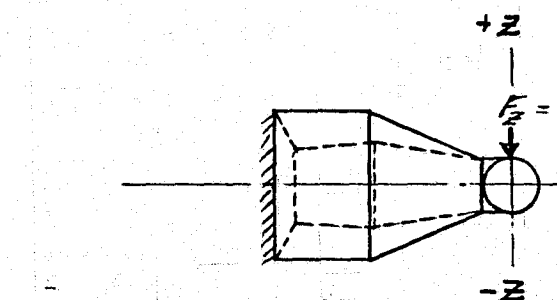
NASA NSC

JOB NO. 5906P

SHEET OF

DATE 2-27-76

BY D. P. RUCKE

FORK TINE DEFLECTION - LOADING IN Z-AXIS

$$* \text{ AVE } I_{Y,Y} = 9.3 \times 10^{-5} \text{ m}^4 \text{ (223 IN}^4\text{)}$$

$$* \text{ AVE } I_{Z,Z} = 4.6 \times 10^{-5} \text{ m}^4 \text{ (110 IN}^4\text{)}$$

$$* \text{ AVE } K = 1.53 \times 10^{-4} \text{ m}^4 \text{ (367 IN}^4\text{)}$$

$$* \text{ AVE } \lambda_Y = 1.60 \text{ (FLEX TO TORSION RATIO)}$$

* SEE SHTS FOR FORK TINE PROPERTIES

CONSIDER TINE AS CURVED CANTILEVER BEAM (SEE REF 5 CASE 15)

DEFLECTION AT LOAD

$$\delta_z = \frac{F_z r^3}{4EI_Y} (B_1 + \lambda B_2)$$

FOR $\phi = 65^\circ$ $\theta = 0^\circ$ (AT LOAD) :

$$B_1 = 1.508 \quad B_2 = .314$$

$$= \frac{2224 (.74)^3}{4(7.31 \times 10^9)(9.3 \times 10^{-5})} [1.508 + 1.60(.314)] = 6.66 \times 10^{-5} \text{ m} \text{ (.0026 IN)}$$

SLOPE AT LOAD (CONSIDER TINE AS SIMPLE CANTILEVER OF LENGTH, l)
 $l = .85 \text{ m (33 IN)}$

$$\theta_z = \frac{F_z l^2}{2EI_Y} = \frac{2224 (.85)^2}{2(7.31 \times 10^9)(9.3 \times 10^{-5})} = 118 \times 10^{-6} \text{ RAD (24"}\text{'')}$$

CASE 15

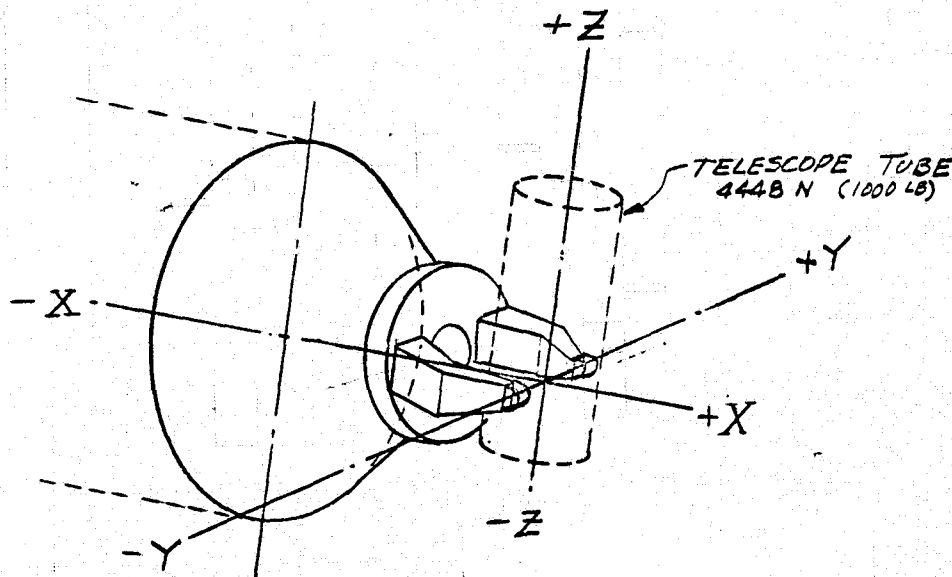
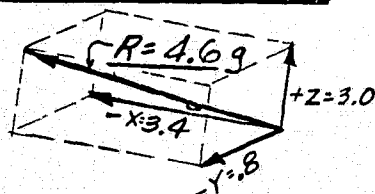
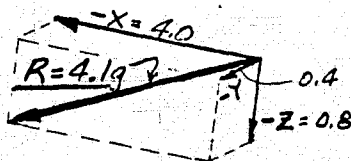
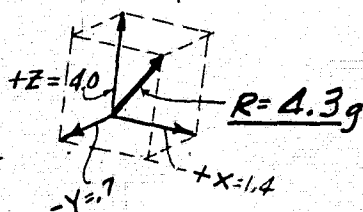
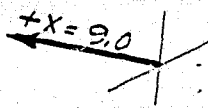
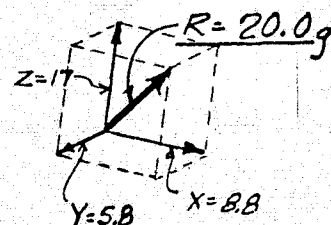
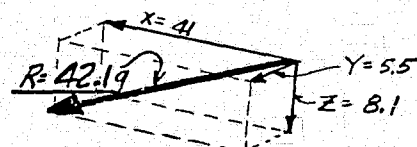
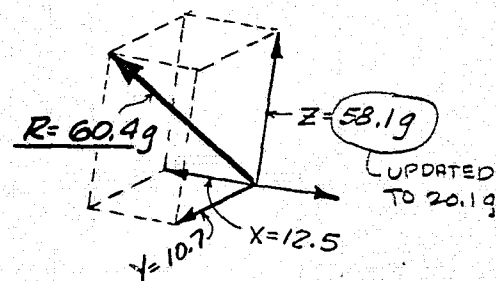
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BOLLER & CHIVENS DIVISION

916 MERIDIAN AVENUE

SOUTH PASADENA, CALIFORNIA 91030

TELEPHONE: (213) 682-3391

DESIGN ANALYSISAEPT FOR SUOTNASA/JSCJOB No. 59064SHEET OF DATE 2-27-76BY D'ROURKESTRESS ANALYSISLOAD CONDITION 1
(LIMIT LOAD FACTORS TABLE S-3 ▽)LAUNCH RELEASESOLID ROCKET CUTOFF-SEPARATIONRE-ENTRYCRASH LANDINGLOAD CONDITION 2
(INCLUDES MECH Q=20 + RANDOM VIB.)

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TELEPHONE: (213) 682-3391

DESIGN ANALYSIS

AFPT FOR SUOT

NASA / JSC

JOB No. 59068

SHEET ____ OF ____

DATE 2-27-76

BY D'ROURKE

STRESS ANALYSISDESIGN LOAD CONDITIONS

BY INSPECTION OF TABLE 5-3 ¹, THE FOLLOWING THREE LOAD CONDITIONS WERE FOUND TO PRODUCE MAXIMUM SINGLE AXIS AND COMBINED AXIS STRESSES:

1. LAUNCH RELEASE
2. SOLID ROCKET MOTOR CUT-OFF-SEPARATION
3. RE-ENTRY

VIBRATION LOADING

STEADY-STATE ACCELERATION HAS BEEN COMBINED WITH DYNAMIC SINUSOIDAL AND RANDOM VIBRATION ACCELERATIONS. THE DYNAMIC ACCELERATIONS OF TABLE 5-3 ¹ ARE REDUCED TO RMS VALUES AND THE "SUM OF THE SQUARES" TAKEN TO FIND THE COMBINED SINUSOIDAL AND RANDOM VIBRATION RMS ACCELERATIONS.

RANDOM VIBRATION ACCELERATIONS

FROM TABLE 5-7 ¹, THE ACCELERATION SPECTRAL DENSITY HAS BEEN PLOTTED AND ANALYSED (SEE SEPARATE GRAPH) FOR ACCELERATION OF A 40 HZ RESONANT SYSTEM OPERATING WITHIN A 10 HZ BANDWIDTH.

$$G = .003 \text{ g}^2/\text{Hz}$$

$$B = 10 \text{ Hz}$$

$$g = .17 \text{ RMS}$$

MECHANICAL AMPLIFICATION FACTOR, Q.

A MECHANICAL AMPLIFICATION FACTOR, Q, OF 20 IS ASSUMED FOR THE LIGHTLY DAMPED STRUCTURAL SYSTEM.

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DESIGN ANALYSISAFPT FOR SUOTNASA / JSCJOB No. 59068SHEET OF DATE 2-27-76BY O COURKESTRESS ANALYSISREPRODUCIBILITY OF THE
ORIGINAL PAGE IS POORNATURAL FREQUENCYTHE SUPPORT STRUCTURE NATURAL FREQUENCIES
FOR THE THREE AXIS OF CONCERN:X - AXIS $f_n = 50.5$ CPSY - AXIS $f_n = 34.5$ CPSZ - AXIS $f_n = 43.5$ CPSDESIGN LOADS (ACCELERATIONS)ASSUME A "WORST CASE CONDITION" WITH THE DYNAMIC
ACCELERATION (RANGE BETWEEN 0-60 HZ) HAPPENING
AT THE APPROXIMATE RESONANT FREQUENCY (40 HZ)
OF THE SUPPORT STRUCTURE $Q = 20$ $g_{RANDOM} = .17 g$ rms1. LAUNCH RELEASEVIBRATION
SINUSOIDAL + RANDOM

	STEADY STATE	$\sqrt{(.707g_{SIN})^2 + g_{RANDOM}^2} \times Q$	TOTAL
X - DIRECTION	- 1.5g	$+ \sqrt{.707^2 + .17^2} \times 20 = .72(20) = 14g$	$= \pm 12.5g$
Y - DIRECTION	$\pm 0.1g$	$+ \sqrt{.5^2 + .17^2} \times 20 = .53(20) = 10.6g$	$= \pm 10.7g$ (max)
Z - DIRECTION	$\pm 0.1g$	$+ \sqrt{2.05^2 + .17^2} \times 20 = 2.9(20) = 58g$	$= \pm 58.1g$ (max)

2. SOLID ROCKET CUT-OFF-SEPARATION

X - DIRECTION	- 1.0g	$+ \sqrt{2.1^2 + .17^2} \times 20 = 2.1(20) = 42g$	$= +41g$ (max)
Y - DIRECTION	$\pm 0.1g$	$+ \sqrt{.21^2 + .17^2} \times 20 = .27(20) = 5.4g$	$= \pm 5.5g$
Z - DIRECTION	$\pm 0.3g$	$+ \sqrt{.35^2 + .17^2} \times 20 = .39(20) = 7.8g$	$= \pm 8.1g$

3. RE-ENTRY

X - DIRECTION	+ 1.0g	$+ \sqrt{.35^2 + .17^2} \times 20 = .39(20) = 7.8g$	$= +8.8g$
Y - DIRECTION	$\pm 0.4g$	$+ \sqrt{.21^2 + .17^2} \times 20 = .27(20) = 5.4g$	$= \pm 5.8g$
Z - DIRECTION	+ 3.0g	$+ \sqrt{.707^2 + .17^2} \times 20 = .72(20) = 14g$	$= +17.0g$

(NOTE: RE-ENTRY LOADS ARE LESS THAN LAUNCH OR ROCKET CUT-OFF)

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BOLLER & CHIVENS DIVISION

910 MERIDIAN AVENUE

SOUTH PASADENA, CALIFORNIA 91030

TELEPHONE: (213) 682-3391

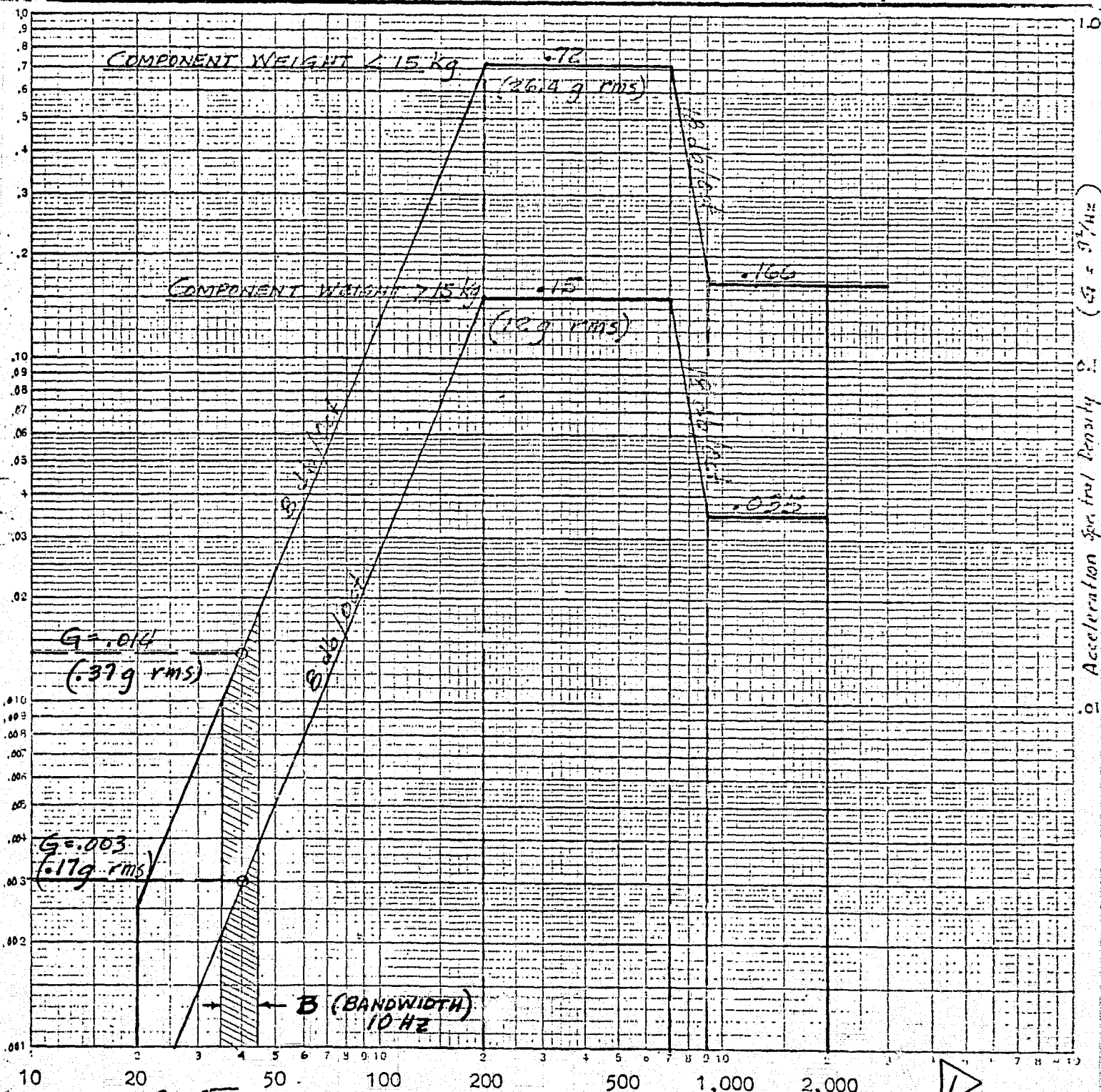
DESIGN ANALYSIS AFPT FOR SVOT
NASA/JSC
RANDOM VIBRATION LEVELS FOR PALLET
PANEL MOUNTED EQUIPMENT

JOB No. 5906P

SHEET OF

DATE 2-27-76

BY J. BOURKE



$g_{rms} = TBG$

Frequency - cycles per second

At $f_n = 40$ Hz & 10 Hz Bandwidth

At $f = 200$ Hz & 10 Hz Bandwidth

WEIGHT > 15 Kg

$g = \sqrt{10(.003)} = .17 g_{rms}$ & $\sqrt{10(.014)} = .37 g_{rms}$

WEIGHT < 15 Kg

$g = \sqrt{10(.15)} = 1.22 g_{rms}$ & $\sqrt{10(.72)} = 2.7 g_{rms}$

FROM TABLE 5-7
SPACELAB PAYLOAD
ACCOMMODATION
HANDBOOK p 5-17

TUSTIN INSTITUTE
OF TECHNOLOGY
P. O. Box 651
Santa Barbara, Cal. 93102

PERKIN-ELMER

BOLLER & CHIVENS DIVISION

916 MERIDIAN AVENUE

SOUTH PASADENA, CALIFORNIA 91030

TELEPHONE: (213) 682-3391

DESIGN ANALYSISA/EPT FOR SUOTNASA / JSCJOB No. 5906PSHEET OF DATE 2-27-76BY O'RourkeSTRESS ANALYSISSTRESS LEVELS FOR OPERATIONAL LOADSEXTREME LOAD CONDITIONS CONSIDERED: RESONANT VIBRATION
AT $Q=20$ 1. LAUNCH RELEASE

$$\begin{aligned} \Sigma X\text{-LOAD} &= 12.5g & (\text{STEADY-STATE} + \text{SIN. VIBRATION} + \text{RANDOM VIBRAT.}) \\ \Sigma Y\text{-LOAD} &= 10.7g & (\text{do}) \\ \Sigma Z\text{-LOAD} &= 58.1g & (\text{do}) \\ WQ &= 20 \end{aligned}$$

1.1 SUPPORT CONE ALUM 2219-T851
 $f_{ty} = 46,000 \text{ LB/IN}^2$

BENDING + AXIAL STRESS

$$f_x = 12.5g @ \frac{2.78 \times 10^6 \text{ N}}{\text{m}^2 g} = 3.47 \times 10^7 \text{ N/m}^2$$

(403 $\frac{\text{LB}}{\text{IN}^2 g}$) (5037 $\frac{\text{LB}}{\text{IN}^2}$)

$$f_y = 10.7g @ \frac{2.22 \times 10^5 \text{ N}}{\text{m}^2 g} = 2.37 \times 10^6 \text{ N/m}^2$$

(32 $\frac{\text{LB}}{\text{IN}^2 g}$) (342 $\frac{\text{LB}}{\text{IN}^2}$)

$$f_z = 58.1g @ \frac{2.22 \times 10^5 \text{ N}}{\text{m}^2 g} = 1.29 \times 10^7 \text{ N/m}^2$$

(32 $\frac{\text{LB}}{\text{IN}^2 g}$) (1,859 $\frac{\text{LB}}{\text{IN}^2}$)

COMBINED BENDING STRESS

$$f_b = \sqrt{f_x^2 + f_y^2 + f_z^2} = \frac{3.71 \times 10^7 \text{ N/m}^2}{(5380 \frac{\text{LB}}{\text{IN}^2})}$$

MARGIN OF SAFETY

$$M.S. = \frac{46,000}{5380} - 1 = \underline{\underline{7.55}}$$

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916 MERIDIAN AVENUE

SOUTH PASADENA, CALIFORNIA 91030

TELEPHONE: (213) 682-3391

DESIGN ANALYSISAFT FOR SUOTNASA / JSCJOB NO. 5906PSHEET OF DATE 2-27-76BY O'RourkeSTRESS ANALYSISSTRESS LEVELS FOR OPERATIONAL LOADSEXTREME LOAD CONDITIONS1. LAUNCH RELEASE (CONT.)KAYDON BRL 6684-1
NON-BRINNELING LOADS

RADIAL = 69,540 LB

AXIAL = 199,430 LB

MOMENT = 1,540,610 LB-IN

1.2 4-PT CONTACT BEARING ΣX -LOAD = 12.5 g AXIAL ONLY ΣY -LOAD = 10.7 g RADIAL & MOMENT ΣZ -LOAD = 58.1 g RADIAL & MOMENT

R UPDATED TO 20.1 g

$$\text{TOTAL AXIAL LOAD } F_x = 12.5g @ 5340 \frac{N}{g} = \frac{6.675 \times 10^4 N}{(15,000 LB)}$$

$$Y\text{-AXIS RADIAL LOAD } F_y = 10.7g @ 5340 \frac{N}{g} = \frac{5.714 \times 10^4 N}{(12,840 LB)}$$

$$Z\text{-AXIS RADIAL LOAD } F_z = 58.1g @ 5340 \frac{N}{g} = \frac{3.103 \times 10^4 N}{(69,720 LB)}$$

$$\text{TOTAL RADIAL LOAD } F_2 = \sqrt{F_y^2 + F_z^2} = \frac{3.16 \times 10^5 N}{(70,935 LB)}$$

$$\text{MOMENT LOAD Y-AXIS } M_y = 10.7g @ 4747 \frac{N \cdot m}{g} = \frac{5.08 \times 10^4 N \cdot m}{(450,800 LB \cdot IN)}$$

$$\text{MOMENT LOAD Z-AXIS } M_z = 58.1g @ 4747 \frac{N \cdot m}{g} = \frac{2.76 \times 10^5 N \cdot m}{(1,339,000 LB \cdot IN)}$$

$$\text{TOTAL MOMENT LOAD } M = \sqrt{M_y^2 + M_z^2} = \frac{2.81 \times 10^5 N \cdot m}{(2.48 \times 10^6 LB \cdot IN)}$$

MARGIN OF SAFETY (SEE NEXT SHT FOR
UPDATED M.S.)

$$M.S. (AXIAL) = \frac{199,430}{15,000} - 1 = 12.29$$

$$M.S. (RADIAL) = \frac{69,540}{70,935} - 1 = -.02$$

$$M.S. (MOMENT) = \frac{1,540,610}{2,480,000} - 1 = -.38$$

NOTE:
SEE NEXT SHEET FOR
UPDATED DESIGN LOADS
AND REDUCED STRESS
LEVELS.

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SOUTH PASADENA, CALIFORNIA 91030

TELEPHONE: (213) 682-3391

DESIGN ANALYSISAFT FOR SUOTNASA / JSCJOB No. 59064SHEET OF DATE 2-27-76BY O'Rourke1.2 4-PT CONTACT BEARING (CONT)

NOTE: UPDATED DESIGN ACCELERATIONS HAVE BEEN RECEIVED SUBSEQUENT TO COMPLETION OF THIS STRESS ANALYSIS.

THE FOLLOWING CORRECTION TO THE BEARING LOAD ANALYSIS IS INCLUDED TO REFLECT THE REDUCED LOAD IN THE Z-AXIS (PRODUCES NEG. MARGIN OF SAFETY)

NEW: DESIGN ACCELERATION IN Z-DIRECTION DURING "LAUNCH RELEASE" FROM "SPACE SHUTTLE SYSTEM PAYLOAD ACCOMMODATION HANDBOOK VOL 14 TABLE 7-6

	<u>DESIGN ACCELERATION Z-DIRECTION</u>
LAUNCH RELEASE:	$\pm 0.1g$ STEADY STATE
(Z-DIRECTION)	$1.4g$ DYNAMIC 0-60 HZ
$Q = 20$	$\pm 1.5g$
$f_z = 43.5 \text{ Hz}$	

DESIGN LOADS - Z-DIRECTION

$$Z = \pm 0.1 + \sqrt{\left[\frac{1.004}{.9791} \cdot (.707)(1.4)^2 + \frac{.029}{.029} \cdot 1.7^2 \times 20 \right]} = \pm 20.1g \quad (\text{WAS } 58.1g)$$

$$\text{Z-AXIS RADIAL LOAD } F_z = 5340 \frac{\text{N}}{g} \times 20.1g = 10.73 \times 10^4 \text{ N} \quad (24,120 \text{ LB})$$

$$\text{TOTAL RADIAL LOAD } F_R = \sqrt{F_y^2 + F_z^2} = \sqrt{(5.714 \times 10^4)^2 + (10.73 \times 10^4)^2} = 1.216 \times 10^5 \text{ N} \quad (27,318 \text{ LB})$$

$$\text{Z-AXIS MOMENT LOAD } M_z = 4747 \frac{\text{N}\cdot\text{m}}{g} \times 20.1g = 9.54 \times 10^4 \text{ N}\cdot\text{m} \quad (644,200 \text{ LB}\cdot\text{IN})$$

$$\text{TOTAL MOMENT LOAD } M = \sqrt{M_y^2 + M_z^2} = \sqrt{(5.08 \times 10^4)^2 + (9.54 \times 10^4)^2} = 1.08 \times 10^5 \text{ N}\cdot\text{m} \quad (953,826 \text{ LB}\cdot\text{IN})$$

$$\text{MARGIN OF SAFETY RADIAL LOAD } M.S. = \frac{69,540}{27,318} - 1 = +1.54 \quad (OK)$$

$$\text{MOMENT LOAD } M.S. = \frac{1,540,610}{844,200} - 1 = +.82 \quad (OK)$$

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916 MERIDIAN AVENUE

SOUTH PASADENA, CALIFORNIA 91030

TELEPHONE: (213) 682-3391

DESIGN ANALYSISA/EPT FOR SUOTNASA / JSCJOB No. 5906PSHEET OF DATE 2-27-76BY O'BURKESTRESS ANALYSISSTRESS LEVELS FOR OPERATIONAL LOADSEXTREME LOAD CONDITIONS1. LAUNCH RELEASE (CONT)1.3 FORK RING

ALUM 2219-TBS1

 $f_{ty} = 46,000 \text{ LB/IN}^2$

$$\Sigma \text{ X-LOAD} = 12.5 \text{ g}$$

$$\Sigma \text{ Y-LOAD} = 10.7 \text{ g}$$

$$\Sigma \text{ Z-LOAD} = 58.1 \text{ g}$$

BENDING STRESS

$$f_x = 12.5 \text{ g} @ \frac{1.147 \times 10^6 \text{ N}}{(166 \frac{\text{LB}}{\text{IN}^2}) \text{ g}} = 1.43 \times 10^7 \frac{\text{N}}{\text{m}^2}$$

$$f_y = 10.7 \text{ g} @ \frac{2.00 \times 10^6 \text{ N}}{(290 \frac{\text{LB}}{\text{IN}^2}) \text{ g}} = 2.14 \times 10^7 \frac{\text{N}}{\text{m}^2}$$

$$f_z = 58.1 \text{ g} @ \frac{2.00 \times 10^6 \text{ N}}{(290 \frac{\text{LB}}{\text{IN}^2}) \text{ g}} = 11.62 \times 10^7 \frac{\text{N}}{\text{m}^2}$$

COMBINED BENDING STRESS

$$f_b = \sqrt{f_x^2 + f_y^2 + f_z^2} = \frac{1.19 \times 10^8 \text{ N/m}^2}{(17,261 \text{ LB/IN}^2)}$$

MARGIN OF SAFETY

$$M.S. = \frac{46,000}{17,261} - 1 = \underline{\underline{1.66}}$$

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TELEPHONE: (213) 682-3391

DESIGN ANALYSISAFPT FOR SUOTNASA / JSCJOB No. 59068SHEET OF DATE 2-27-76BY O'RourkeSTRESS ANALYSISSTRESS LEVELS FOR OPERATIONAL LOADSEXTREME LOAD CONDITIONS1. LAUNCH RELEASE (CONT)1.4 FORK TIME

ALUM 2219-T851

$$f_{ty} = 46,000 \text{ LB/IN}^2$$

$$\Sigma X - \text{LOAD} = 12.5 g$$

$$\Sigma Y - \text{LOAD} = 10.7 g$$

$$\Sigma Z - \text{LOAD} = 58.1 g$$

BENDING STRESS + AXIAL STRESS

$$f_x = 12.5 g @ \frac{4.2 \times 10^5 \frac{N}{m^2} g}{(61 \text{ LB/IN}^2 g)} = 5.25 \times 10^6 \frac{N}{m^2}$$

$$f_y = 10.7 g @ \frac{5.51 \times 10^6 \frac{N}{m^2} g}{(799.7 \text{ LB/IN}^2 g)} = 5.90 \times 10^7 \frac{N}{m^2}$$

$$f_z = 58.1 g @ \frac{4.54 \times 10^6 \frac{N}{m^2} g}{(659 \text{ LB/IN}^2 g)} = 2.64 \times 10^8 \frac{N}{m^2}$$

COMBINED TENSILE STRESS

$$f_t = \sqrt{f_x^2 + f_y^2 + f_z^2} = \frac{2.71 \times 10^8 \frac{N}{m^2}}{(39,240 \text{ LB/IN}^2)}$$

MARGIN OF SAFETY

$$M.S. = \frac{46,000}{39,240} - 1 = \underline{\underline{0.17}}$$

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SOUTH PASADENA, CALIFORNIA 91030

TELEPHONE: (213) 682-3391

DESIGN ANALYSISAFT FOR SUDTNASA/JSCJOB No. 59068SHEET OF DATE 2-27-76BY D'ROURKESTRESS ANALYSISSTRESS LEVELS FOR OPERATIONAL LOADSEXTREME LOAD CONDITIONS CONSIDERED: RESONANT VIBRATIONS
AT $Q = 20$ 2. SOLID ROCKET CUT-OFF-SEPARATION2.1 SUPPORT CONE

ALUM 2219-T851

$$f_{ty} = 46,000 \text{ LB/IN}^2$$

$$\Sigma X\text{-LOAD} = 41g$$

$$\Sigma Y\text{-LOAD} = 5.5g$$

$$\Sigma Z\text{-LOAD} = 8.1g$$

BENDING + AXIAL STRESS

$$f_x = 41g @ 2.78 \times 10^6 \frac{\text{N}}{\text{m}^2g} = 1.14 \times 10^8 \text{ N/m}^2$$

$$f_y = 5.5g @ 2.22 \times 10^5 \frac{\text{N}}{\text{m}^2g} = 1.21 \times 10^6 \text{ N/m}^2$$

$$f_z = 8.1g @ 2.22 \times 10^5 \frac{\text{N}}{\text{m}^2g} = 1.78 \times 10^6 \text{ N/m}^2$$

COMBINED TENSILE STRESS

$$f_t = \sqrt{f_x^2 + f_y^2 + f_z^2} = \frac{1.14 \times 10^8 \text{ N/m}^2}{16,500 \text{ LB/IN}^2}$$

MARGIN OF SAFETY

$$M.S. = \frac{46,000}{16,500} - 1 = \underline{\underline{1.79}}$$

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TELEPHONE: (213) 682-3391

DESIGN ANALYSISA/EPT FOR SUOTNASA / JSCJOB No. 5906PSHEET OF DATE 2-27-76BY O'RourkeSTRESS ANALYSISSTRESS LEVELS FOR OPERATIONAL LOADSEXTREME LOAD CONDITIONS2.0 SOLID ROCKET CUT-OFF - SEPARATION (CONT)2.2 4-PT CONTACT BEARING (52100 STL)

$$\begin{aligned}\Sigma X\text{-LOAD} &= 41\text{ g} \\ \Sigma Y\text{-LOAD} &= 5.5\text{ g} \\ \Sigma Z\text{-LOAD} &= 8.1\text{ g}\end{aligned}$$

$$\text{TOTAL AXIAL LOAD } F_x = 41\text{ g} @ 5340 \frac{\text{N}}{\text{g}} = \frac{2.19 \times 10^5 \text{ N}}{(49,200 \text{ LB})}$$

$$\text{RADIAL LOADS Y-AXIS } F_y = 5.5\text{ g} @ 5340 \frac{\text{N}}{\text{g}} = 2.94 \times 10^4 \text{ N}$$

$$\text{Z-AXIS } F_z = 8.1\text{ g} @ 5340 \frac{\text{N}}{\text{g}} = 4.32 \times 10^4 \text{ N}$$

$$\text{TOTAL RADIAL LOAD } F_R = \sqrt{F_y^2 + F_z^2} = \frac{5.23 \times 10^4 \text{ N}}{(11,758 \text{ LB})}$$

$$\text{MOMENT LOAD Y-AXIS } M_y = 5.5\text{ g} @ 4747 \frac{\text{N}\cdot\text{m}}{\text{g}} = 2.61 \times 10^4 \text{ N}\cdot\text{m}$$

$$\text{Z-AXIS } M_z = 8.1\text{ g} @ 4747 \frac{\text{N}\cdot\text{m}}{\text{g}} = 3.85 \times 10^4 \text{ N}\cdot\text{m}$$

$$\text{TOTAL MOMENT LOAD } M = \sqrt{M_y^2 + M_z^2} = \frac{4.65 \times 10^4 \text{ N}\cdot\text{m}}{(10,448 \text{ LB}\cdot\text{IN})}$$

MARGIN OF SAFETY

$$M.S. (\text{AXIAL}) = \frac{199,430}{49,200} - 1 = 3.05$$

$$M.S. (\text{RADIAL}) = \frac{69,540}{11,758} - 1 = 4.91$$

$$M.S. (\text{MOMENT}) = \frac{1,540,000}{10,448} - 1 = 146.4$$

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SOUTH PASADENA, CALIFORNIA 91030

TELEPHONE: (213) 682-3391

DESIGN ANALYSISAFT FOR SUOTNASA / SSCJOB No. 5906PSHEET OF DATE 2-27-76BY O'RourkeSTRESS ANALYSISSTRESS LEVELS FOR OPERATIONAL LOADSEXTREME LOAD CONDITIONS2.0 SOLID ROCKET CUT-OFF-SEPARATION (CONT)2.3 FORK RING

ALUM 2219-T851

 $f_{ty} = 46,000 \text{ LB/IN}^2$

$$\Sigma \text{ X-LOAD} = 41g$$

$$\Sigma \text{ Y-LOAD} = 5.5g$$

$$\Sigma \text{ Z-LOAD} = 8.1g$$

BENDING STRESS

$$f_x = 41g @ 1.147 \times 10^6 \frac{\text{N}}{\text{m}^2g} = 4.70 \times 10^7 \frac{\text{N}}{\text{m}^2}$$

$$f_y = 5.5g @ 2.00 \times 10^6 \frac{\text{N}}{\text{m}^2g} = 1.10 \times 10^7 \frac{\text{N}}{\text{m}^2}$$

$$f_z = 8.1g @ 2.00 \times 10^6 \frac{\text{N}}{\text{m}^2g} = 1.62 \times 10^7 \frac{\text{N}}{\text{m}^2}$$

COMBINED BENDING STRESS

$$f_b = \sqrt{f_x^2 + f_y^2 + f_z^2} = \frac{5.09 \times 10^7 \frac{\text{N}}{\text{m}^2}}{(7384 \text{ LB/IN}^2)}$$

MARGIN OF SAFETY

$$M.S. = \frac{46,000}{7,384} - 1 = \underline{\underline{5.23}}$$

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BOLLER & CHIVENS DIVISION

916 MERIDIAN AVENUE

SOUTH PASADENA, CALIFORNIA 91030

TELEPHONE: (213) 682-3391

DESIGN ANALYSISDEPT FOR SUOTNASA / JSCJOB No. 5906PSHEET OF DATE 2-27-76BY D'KURKESTRESS ANALYSISSTRESS LEVEL FOR OPERATIONAL LOADSEXTREME LOAD CONDITIONS2.0 SOLID ROCKET CUT-OFF-SEPARATION (CONT)2.4 FORK TIME

ALUM 2219-T851

$$f_{ty} = 46,000 \text{ } ^L\text{B}/\text{IN}^2$$

$$\Sigma X - \text{LOAD} = 41g$$

$$\Sigma Y - \text{LOAD} = 5.5g$$

$$\Sigma Z - \text{LOAD} = 8.1g$$

BENDING AND AXIAL STRESS

$$f_x = 41g @ 4.2 \times 10^5 \frac{\text{N}}{\text{m}^2g} = 1.72 \times 10^7 \text{ } ^N\text{m}^2$$

$$f_y = 5.5g @ 5.51 \times 10^6 \frac{\text{N}}{\text{m}^2g} = 3.03 \times 10^7 \text{ } ^N\text{m}^2$$

$$f_z = 8.1g @ 4.54 \times 10^6 \frac{\text{N}}{\text{m}^2g} = 3.68 \times 10^7 \text{ } ^N\text{m}^2$$

COMBINED TENSILE STRESS

$$f_t = \sqrt{f_x^2 + f_y^2 + f_z^2} = \frac{5.07 \times 10^7 \text{ } ^N\text{m}^2}{(7,347 \text{ } ^L\text{B}/\text{IN}^2)}$$

MARGIN OF SAFETY

$$M.S. = \frac{46,000}{7,347} - 1 = \underline{5.26}$$

PERKIN-ELMER

BOLLER & CHIVENS DIVISION

916 MERIDIAN AVENUE

SOUTH PASADENA, CALIFORNIA 91030

TELEPHONE: (213) 682-3391

DESIGN ANALYSIS

AFPT FOR SUOT

NASA / JSC

JOB No. 59068

SHEET OF

DATE 2-27-76

BY O'Rourke

STRESS ANALYSIS - LOADING IN X-AXIS - 1g LOADSUPPORT CONESEE DEFLECTION CALC'S FOR
LOADING AND GEOMETRYMAX STRESS (AS A BELLEVILLE SPRING) (WORST CASE)

$$f_b = \frac{E \delta C_1 h}{(1-\nu^2) M a^2}$$

$$\nu = \text{POISSON'S RATIO} = .33$$

$$M = \text{CONSTANT} = .79 \quad @ \quad a/b = 3.14$$

$$C_1 = \text{CONSTANT} = 1.46 \quad @ \quad a/b = 3.14$$

$$\delta = 9.55 \times 10^{-5} \text{ m (from Deflection Calc's)}$$

$$= \frac{(7.31 \times 10^{10})(9.55 \times 10^{-5})(1.46)(.80)}{(1-.33^2)(.79)(2.04^2)} = \underline{2.78 \times 10^6 \text{ N/m}^2} \quad (403 \text{ lb/in}^2) @ 1g.$$

2
Rev
P254

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TELEPHONE: (213) 682-3391

DESIGN ANALYSISAEPT FOR SUOTNASA / JSCJOB No. 59068SHEET OF DATE 2-27-76BY O'POURKESTRESS ANALYSIS - LOADING IN X-AXIS - 1g LOADOUTER BEARINGKaydon No 6684-1 with .0005 in Preload
axial preload Relieved at 4800 LBAXIAL LOAD $F_x = 5340 \text{ N (1200 LB)}$

$$M.S. = \frac{4800}{1200} - 1 = 3.0$$

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DESIGN ANALYSISAFPT FOR SUOTNASA / JSCJOB No. 5906PSHEET OF DATE 2-27-76BY O'RourkeSTRESS ANALYSIS - LOADING IN X-AXIS - 1g LOADFORK RING

(SEE DEFLECTION ANALYSIS FOR CONFIGURATION)

5
Case 1

$$\text{MOMENT } M = \frac{T_0 \sin \theta}{2} = \frac{972 (1)}{2} = 486 \text{ N}\cdot\text{m} @ \theta = 90^\circ$$

$$\text{TORQUE } T = \frac{T_0 \cos \theta}{2} = \frac{972 (1)}{2} = 486 \text{ N}\cdot\text{m} @ \theta = 0^\circ$$

MAX BENDING STRESS

$$f_b = \frac{Mc}{I_y} = \frac{486 (.106)}{4.49 \times 10^{-5}} = 1.147 \times 10^6 \text{ N/m}^2 \quad (166 \text{ LB/IN}^2) @ 1g.$$

MAX TORSIONAL STRESS

2
Perk
Case 9
p125

$$f_s = \frac{T}{2tA} = \frac{486}{2(.013)(.046)} = 4.06 \times 10^5 \text{ N/m}^2 \quad (59 \text{ LB/IN}^2) @ 1g.$$

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DESIGN ANALYSISA/EPT FOR SUOTNASA / ISCJOB No. 5906PSHEET OF DATE 2-27-76BY O'POURKESTRESS ANALYSIS - LOADING IN X-AXIS - 1g LOADFORK TINE (SEE DEFLECTION CALC'S FOR GEOMETRY)COLUMN LOAD $F_x = 2224 \text{ N (500 LB)}$ AXIAL STRESS $f_a = \frac{F_x}{A} = \frac{2224}{.0053} = \underline{\underline{4.20 \times 10^5 \text{ N/m}^2}} \text{ (61 } \frac{\text{LB}}{\text{IN}^2}) @ 1g$

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TELEPHONE: (213) 682-3391

DESIGN ANALYSIS

A/EPT FOR SUOT

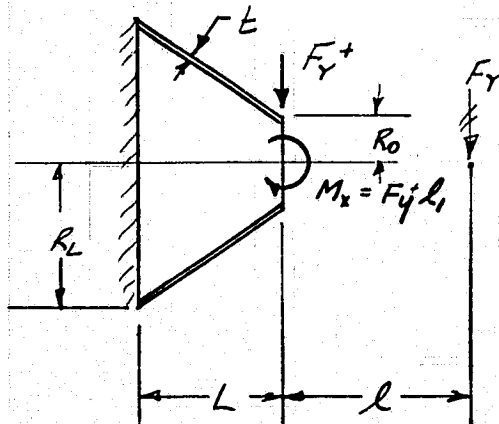
NASA / JSC

JOB No. 5906P

SHEET OF

DATE 2-27-76

BY O'Rourke

STRESS ANALYSIS - LOADING IN Y-AXIS - 1g LOADSUPPORT CONE

$$C_0 = 3.14$$

$$l = .95m (37.5)$$

$$R_0 = .65m (25.6in)$$

$$R_L = 2.04m (80.45in)$$

$$L = .80m (31.5)$$

$$t = .0035m (.139in)$$

$$F_Y = 4448 N (1000 LB) @ 1g$$

$$F_{Y+} = 5340 N (1200 LB) @ 1g$$

$$M = F_{Y+} l = 5086 N \cdot m @ 1g$$

BENDING STRESS FROM MOMENT, M @ 1g

$$f_b = \pm \frac{M}{C_0 t R_L^2} = \pm \frac{5086}{3.14 (.0035)(2.04^2)} = \pm 1.112 \times 10^5 N/m^2 (16 LB/in^2) @ 1g$$

BENDING STRESS FROM END LOAD, Fy+ (@ 1g)

$$f_b = \pm \frac{F_Y L}{C_0 t R_L^2} = \pm \frac{5086}{3.14 (.0035)(2.04^2)} = \pm 1.112 \times 10^5 N/m^2 (16 LB/in^2) @ 1g$$

TOTAL BENDING STRESS

$$f_b = 2.224 \times 10^5 N/m^2 (32 LB/in^2) @ 1g$$

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DESIGN ANALYSISAFT FOR SUOTNASA / JSCJOB No. 5906PSHEET OF DATE 2-27-76BY O'RourkeSTRESS ANALYSIS - LOADING IN Y-AXIS - 1g LOAD

KAYDON NO. 6684-1 4-point BEARING

OUTER BEARING

.0005 IN. PRELOAD PRELOAD RELIEVED AT 162,000 LB-IN

RADIAL PRELOAD RELIEVED AT 31,000 LB

MOMENT LOADING

$$M = F_y L = 5340(1.89) = 4747 \text{ N}\cdot\text{m}$$

(42,000 LB-IN)

@ 1g

$$@ 1g \quad M.S. = \frac{162,000}{42,000} = 3.86$$

RADIAL LOADING

$$F_y = 5340 \text{ N} (1200 \text{ LB}) @ 1g$$

$$@ 1g \quad M.S. = \frac{31,000 \text{ LB}}{1200 \text{ LB}} = 25.83$$

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DESIGN ANALYSISAEP T FOR SUOTNASA / JSCJOB No. 59068SHEET OF DATE 2-27-76BY O'RourkeSTRESS ANALYSIS - LOADING IN Y-AXIS - 1g LOADFORK RING (SEE DEFLECTION ANALYSIS FOR CONFIGURATION)

MOMENT $M = \frac{T_0 \sin \theta}{2} = \frac{1695.5 (1)}{2} = 847.75 \text{ N.m @ } \theta = 90^\circ$

TORQUE $T = \frac{T_0 \cos \theta}{2} = \frac{1695.5 (1)}{2} = 847.75 \text{ N.m @ } \theta = 0^\circ$

MAX BENDING STRESS @ $\theta = 90^\circ$

$$f_b = \frac{Mc_y}{I_y} = \frac{847.75 (.106)}{4.49 (10^{-5})} = 2.00 \times 10^6 \text{ N/m}^2 \quad (290 \text{ LB/IN}^2) @ 1g$$

MAX TORSIONAL STRESS @ $\theta = 0^\circ$

$$f_s = \frac{T}{2tA} = \frac{847.75}{2(.013)(.04636)} = 7.03 \times 10^5 \text{ N/m}^2 \quad (102 \text{ LB/IN}^2) @ 1g$$

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CASE
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2
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CASE 9
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DESIGN ANALYSISAFT FOR SUOTNASA / JSCJOB No. 5906PSHEET OF DATE 2-27-76BY O'DRURKESTRESS ANALYSIS - LOADING IN Y-AXIS 1-g LOADFORK TINES (SEE DEFLECTION CALC'S FOR GEOMETRY)BENDING STRESS

$$f_b = \frac{Mc}{I_z} = \frac{FyLc}{I_z} = \frac{2224(.83)(.137)}{4.6(10^{-5})} = \frac{5.51 \times 10^6 \text{ N/m}^2}{(799.7 \text{ LB/IN}^2)}$$

@ 1g

SA-Z-1

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DESIGN ANALYSISAFPT FOR SUOTNASA/JSCJOB No. 59068SHEET OF DATE 2-27-76BY O'ROURKESTRESS ANALYSIS - LOADING IN Z-AXIS - 1g LOADSUPPORT CONE

SAME LOADING AND STRESS
AS LOADING IN THE Y-AXIS

BENDING STRESS $f_b = 2.224 \times 10^5 \text{ N/m}^2 \text{ (32 LB/IN}^2\text{) @ 1g}$

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DESIGN ANALYSISAFPT FOR SUOTNASA / JSCJOB No. 5906P

SKETCH OF _____

DATE 2-27-76BY O'RourkeSTRESS ANALYSIS - LOADING IN Z-AXIS - 1g LOADOUTER BEARING

SAME AS LOADING IN Y-AXIS
 SAME STRESS

MOMENT LOADING

$$@ 1g \quad M.S. = \frac{162,000 \text{ LB-IN}}{42,000 \text{ LB-IN}} = 3.86$$

RADIAL LOADING

$$@ 1g \quad M.S. = \frac{31,000 \text{ LB}}{1200 \text{ LB}} = 25.83$$

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DESIGN ANALYSIS

AFPT For SUOT

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JOB No. 5906P

SHEET OF

DATE 2-27-76

BY O'ROURKE

STRESS ANALYSIS - LOADING IN Z-AXIS - 1g LOADFORK RINGSEE DEFLECTION ANALYSIS
FOR CONFIGURATIONBENDING MOMENT @ $\theta = 90^\circ$

$$M = \frac{Rr (\sin \theta - \cos \theta)}{2} = \frac{5652(.3)(1-0)}{2} = 847.8 \text{ N.m}$$

TWISTING MOMENT @ $\theta = 45^\circ$

$$T = \frac{Rr (\sin \theta + \cos \theta - 1)}{2} = \frac{5652(.3)(.707 + .707 - 1)}{2} = 351 \text{ N.m}$$

MAX BENDING STRESS @ $\theta = 90^\circ$

$$f_b = \frac{Mc}{I_y} = \frac{847.8(.106)}{4.49 \times 10^{-5}} = 2.00 \times 10^6 \text{ N/m}^2 \quad (290 \text{ LB/IN}^2) @ 1g.$$

MAX TORSIONAL STRESS @ $\theta = 45^\circ$

$$f_s = \frac{T}{2tA} = \frac{351}{2(.013)(.046)} = 2.93 \times 10^5 \text{ N/m}^2 \quad (42 \text{ LB/IN}^2) @ 1g.$$

5
Case 32
Link
Case 9
p195

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TELEPHONE: (213) 682-3391

DESIGN ANALYSIS

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JOB No. 5906P

SHEET OF

DATE 2-27-76

BY O'Rourke

STRESS ANALYSIS - LOADING IN Z-AXIS - 1g LOADFORK TINES (SEE DEFLECTION CALC'S FOR GEOMETRY)BENDING STRESS

$$f_b = \frac{M_c}{I_y} = \frac{F \cdot L \cdot c}{I_y} = \frac{2224(.83)(.229)}{9.3 \times 10^{-5}} = 4.54 \times 10^6 \text{ N/m}^2 @ 1g.$$

(659 LB/IN²)

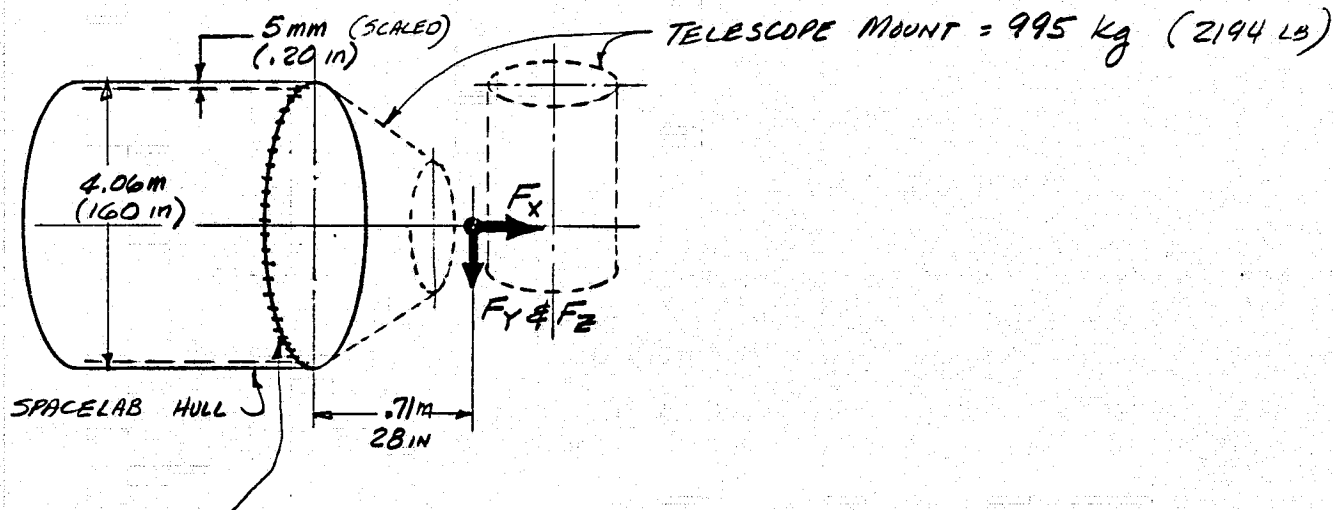
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SOUTH PASADENA, CALIFORNIA 91030
TELEPHONE: (213) 682-3391

TELES. MOUNT REACTION ON
SPACELAB

DESIGN ANALYSIS - AFPT FOR SUOT
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JOB No. 5906P
SHEET 1 OF 1
DATE 2-27-76
BY O'Rourke



MOUNTING BOLTS (ASSUMED) NO INFORMATION AVAILABLE

P.D. = 4.084 m (160.8 in)
N = 144 BOLTS (2.5° APART)
p = 89.1 mm (3.51 in.)

BOLT SIZE $\approx$ 9mm

Minor dia = 7.9

Stress AREA $\approx$ 49 mm² (.0759 in²)

TOTAL AREA $A_T \approx 144 (49) = 7056 \text{ mm}^2$ (10.94 in²)

PRESSURE LOAD ON END CONE

$$P = 15 \frac{\text{LB}}{\text{IN}^2} \left(\frac{160^2}{4} \right) \pi = 301,592 \text{ LB}$$

$$\text{BOLT STRESS} \approx \frac{301,592}{10.94} = 27,575 \frac{\text{LB}}{\text{IN}^2}$$

ASSUME GRADE 12.9 Tensile = 170,000 $\frac{\text{LB}}{\text{IN}^2}$ YIELD = 153,000 $\frac{\text{LB}}{\text{IN}^2}$
Shear = .6 YIELD = 91,800 $\frac{\text{LB}}{\text{IN}^2}$

MOMENT LOADING ON SPACELAB FROM TELESCOPE MOUNT

MAX $F_y = 2194 \text{ LB} @ 10.7g$ DURING LAUNCH RELEASE

MAX $M_y = 2194 \times 10.7 @ 28 \text{ in} = 657,322 \text{ LB-IN}$

SECTION MODULUS OF BOLT PATTERN

$$\text{BOLT LINEAR AREA } A_B = \frac{.0759 \text{ in}^2}{3.51 \text{ in}} = .0216 \frac{\text{in}^2}{\text{in}} = .0216 \text{ in EFFECTIVE THICKNESS}$$

(CONT)

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TELES. MOUNT REACTION ON
SPACELAB

DESIGN ANALYSIS

AFPT FOR SUOT NASA/JSC

JOB No. 5406P

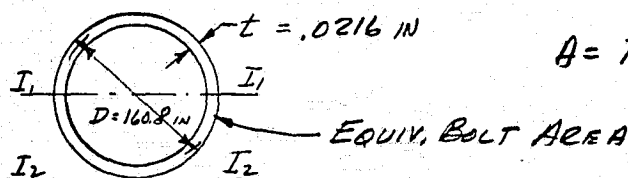
SHEET 2 OF

DATE 2-27-76

BY D'ROURKE

MOMENT OF INERTIA OF BOLT PATTERN : (PIVOT AT BOTTOM FLANGE)

ASSUME BOLTS FORM TUBE OF 160.8 IN DIA X .0216 IN. THK



$$A = \pi (160.8) (.0216) = 10.91 \text{ IN}^2$$

$$I_1 = .4 D^3 t = .4 (160.8)^3 (.0216) = 35,923 \text{ IN}^4$$

$$I_2 = I_1 + \frac{A D^2}{4} = 35,923 + \frac{10.91 (160.8)^2}{4} = 106,457 \text{ IN}^4$$

SEC. MODULUS OF BOLT PATTERN (ABOUT BOTTOM OF FLANGE)

$$S = \frac{I}{D} = \frac{106,457}{160.8} = 662 \text{ IN}^3$$

TENSILE STRESS IN BOLTS FROM MOMENT LOAD (10.7 g's)

$$f_b = \frac{M}{S} = \frac{657,322 \text{ LB-IN}}{662 \text{ IN}^3} = \underline{1,057 \frac{\text{LB}}{\text{IN}^2}} @ 10.7 \text{ g's}$$

SECTION MODULUS OF SPACELAB HULL

$$S = .8 D^2 t = .8 (160)^2 (.20) = 4096 \text{ IN}^3$$

STRESS IN HULL FROM MOMENT LOADING (10.7 g's)

$$f_b = \frac{M}{S} = \frac{657,322 \text{ LB-IN}}{4096 \text{ IN}^3} = \underline{160 \text{ LB/IN}^2} @ 10.7 \text{ g's}$$

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SOUTH PASADENA, CALIFORNIA 91030

TELEPHONE: (213) 682-3391

TELESCOPE MOUNT REACTION

ON SPACELAB

DESIGN ANALYSIS

AEPT FOR SVOT NASA/JSC

JOB NO. 5906P

SHEET 3 OF

DATE 2-27-76

BY O'ROURKE

AXIAL LOADING ON SPACELAB FROM TELESCOPE MOUNT

ASSUME AXIAL LOAD AT LAUNCH RELEASE = 12.5 g
(THIS LOAD WILL COMBINE WITH MOMENT LOAD
OF 10.7 g's)

$$F_x = 2,194 \text{ LB} \times 12.5 = 27,425 \text{ LB}$$

TENSILE STRESS IN BOLTS FROM AXIAL LOAD

$$f_a = \frac{F_x}{A_b} = \frac{27,425 \text{ LB}}{10.94 \text{ IN}^2} = \underline{2,507 \text{ LB/IN}^2} @ 12.5 \text{ g's}$$

TENSILE STRESS IN HULL FROM AXIAL LOAD

$$f_a = \frac{F_x}{A_h} = \frac{27,425 \text{ LB}}{160(\pi)(.2)} = \frac{27,425 \text{ LB}}{100.5 \text{ IN}^2} = \underline{273 \text{ LB/IN}^2} @ 12.5 \text{ g's}$$

COMBINED STRESSES AT LAUNCH RELEASE FROM TELESCOPE

$F_y @ 10.7 \text{ g's}$
 $F_x @ 12.5 \text{ g's}$

MAX BOLT STRESS (ATTACHMENT TO HULL)

$$f_b = \overset{\text{MOMENT}}{1,057} + \overset{\text{AXIAL}}{2,507} = \underline{3,564 \text{ LB/IN}^2}$$

(13% OF PRESS. STRESS)

BOLT STRESS FROM 15 PSI PRESSURE INSIDE HULL

$$f = \frac{301,592}{10.94 \text{ IN}^2} = 27,575 \text{ LB/IN}^2$$

BOLT AREA

MAX HULL STRESS

$$f_h = \overset{\text{MOMENT}}{160} + \overset{\text{AXIAL}}{273} = \underline{433 \text{ LB/IN}^2}$$

(14% OF PRESS. STRESS)

HULL STRESS FROM 15 PSI PRESSURE INSIDE HULL

$$f = \frac{301,592 \text{ LB}}{100.5 \text{ IN}^2} = 3,000 \text{ LB/IN}^2$$

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TELEPHONE: (213) 682-3391

DESIGN ANALYSIS

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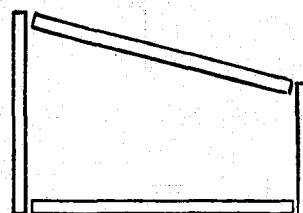
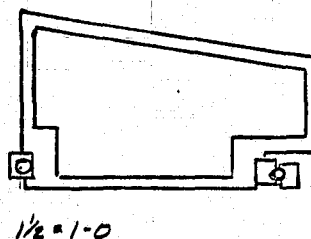
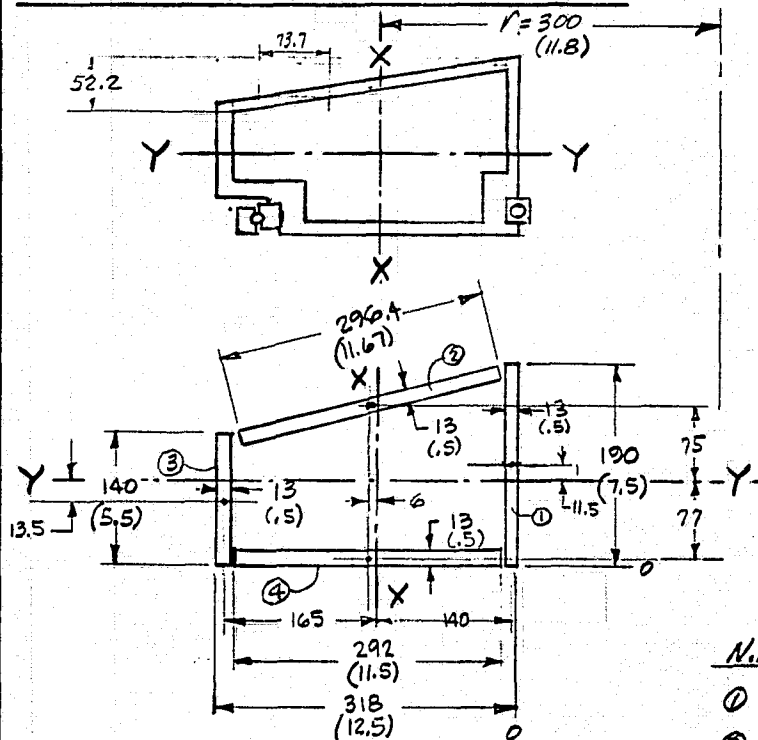
JOB No. 5906F

SHEET OF

DATE 2-27-76

BY O'ROURKE

FORK RING - PROPERTIES



MOMENTS OF INERTIA

I_{x-y}	I_o	A	d_x	Ad^2
① $\frac{13(190^3)}{12} =$	39,108	2470	11.5	326,657
② $\frac{23.7(52.2^3)}{12} =$	16,735	3848	75	21,645,000
③ $\frac{13(140^3)}{12} =$	21,233	1820	13.5	331,695
④ $\frac{292(13^3)}{12} =$	4,112	3796	77	22,506,484
	81,188			44,809,836

$$I_{x-y} = \sum I_o + \sum Ad_x^2 = \frac{44.9 \times 10^6 \text{ mm}^4}{4.49 \times 10^{-5} \text{ m}^4} (107.9 \text{ IN}^4)$$

I_{x-x}	I_o	A	d_x	Ad^2
① $\frac{190(13^3)}{12} =$	2,676	2470	140	48,412,000
② $\frac{13(296^3)}{12} =$	94,917	3848	6	138,528
③ $\frac{140(13^3)}{12} =$	1,972	1820	165	49,549,500
④ $\frac{13(292^3)}{12} =$	92,369	3796	6	136,656
	191,934			98,236,684

$$I_{x-x} = \sum I_o + \sum Ad_x^2 = \frac{98.4 \times 10^6 \text{ mm}^4}{9.84 \times 10^{-5} \text{ m}^4} (236.4 \text{ IN}^4)$$

N.A.	AREA	Y	AY	X	AX
① $13 \times 190 =$	2470	6.5	16055	95	234,650
② $13 \times 296 =$	3848	152.5	586,820	158.5	609,908
③ $13 \times 140 =$	1820	311.5	566,930	70	127,400
④ $13 \times 292 =$	3796	152.5	578,890	6.5	24,674
	11,934 mm ²		1,748,695		996,632

$$N.A. X-X = \frac{1,748,695}{11,934} = 146.5 (5.77)$$

$$N.A. Y-Y = \frac{996,632}{11,934} = 83.5 (3.29) \quad C_y = 190 - 83.5 = 106.5 \text{ mm}$$

TORSIONAL SHAPE FACTOR

ROARK 4th ED. CASE 9 p 195

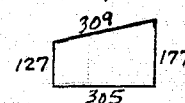
K = Torsional Shape factor

$$U = \text{Length of median boundary} = 305 + 177 + 309 + 127 = 918 \text{ mm}$$

$$A = \text{Area within median boundary} = \left(\frac{177 - 127}{2} + 127 \right) (305) = 46,360 \text{ mm}^2$$

$$t = \text{Wall thickness} = 13$$

$$K = \frac{4A^2t}{U} = \frac{4(46,360)^2(13)}{918} = 121.7 \times 10^6 \text{ mm}^4 = 1.217 \times 10^{-4} \text{ m}^4 (292.4 \text{ IN}^4)$$



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SOUTH PASADENA, CALIFORNIA 91030

TELEPHONE: (213) 682-3391

DESIGN ANALYSIS

A/EPT FOR SUOT

NASA / JSC

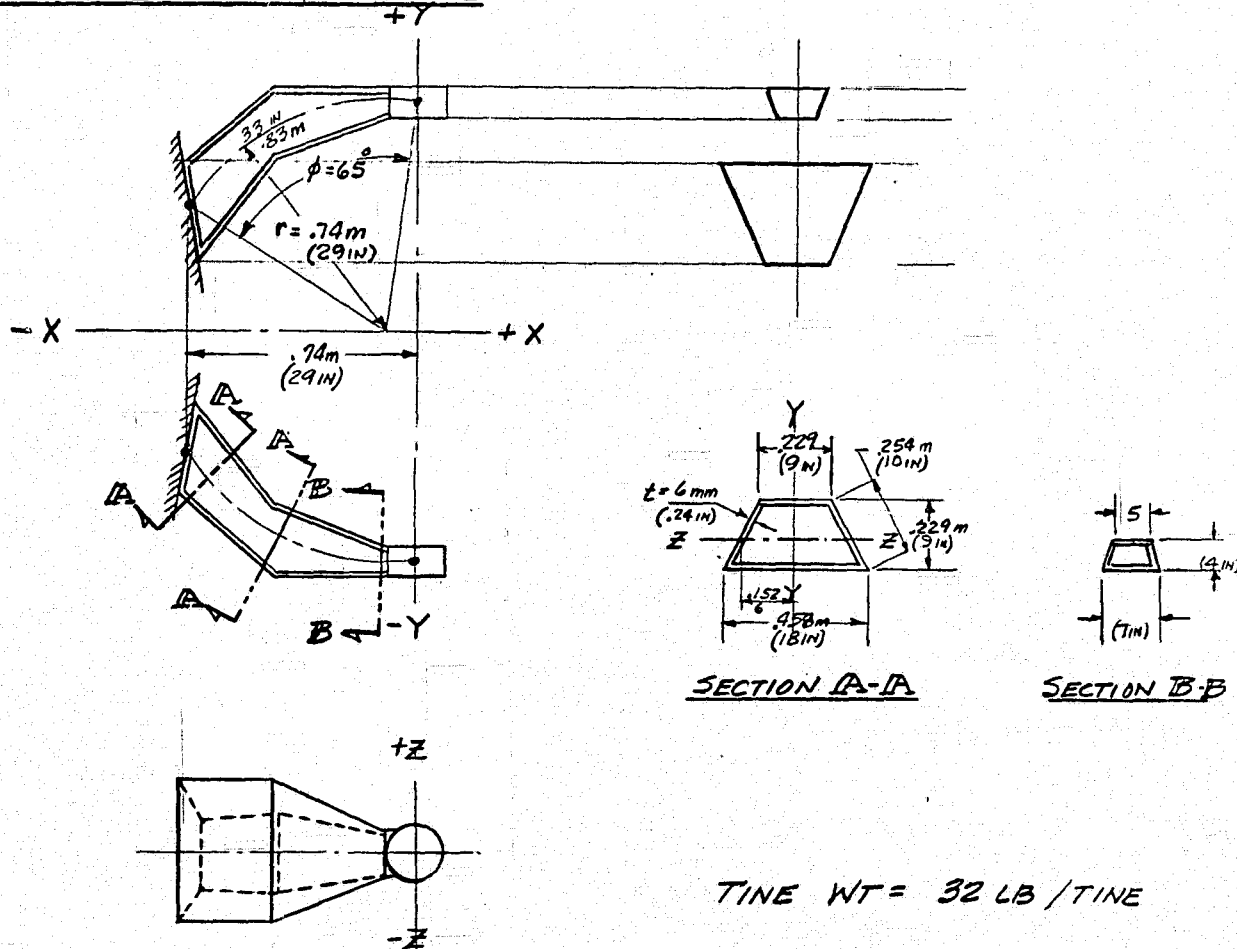
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SHEET OF

DATE 2-27-76

BY D. ROURE

FORK TINE - PROPERTIES



TINE WT = 32 LB / TINE

AT SECTION A-A

$$I_{Y-Y} \approx \frac{.006(.458^3)}{12} + \frac{.006(.229)^3}{12} + .006(.254)(.152^2)(2) = 4.8 \times 10^{-5} + .60 \times 10^{-5} + 7.0 \times 10^{-5} = 12.4 \times 10^{-5} m^4$$

$$I_{Z-Z} \approx \frac{.006(.229^3)}{12} + .006(.229)(.127^2) + .006(.458)(.102^2) = 1.2 \times 10^{-5} + 2.2 \times 10^{-5} + 2.8 \times 10^{-5} = 6.2 \times 10^{-5} m^4$$

AVERAGE MOMENT OF INERTIA, CONSIDERING TAPER IN LAST SECTION OF TINE, WILL BE APPROXIMATELY 75% OF THAT AT SECTION A-A

$$AVE. I_{Y-Y} = .75(12.4 \times 10^{-5}) = \underline{9.3 \times 10^{-5} m^4} \quad (223 in^4)$$

$$AVE. I_{Z-Z} = .75(6.2 \times 10^{-5}) = \underline{4.6 \times 10^{-5} m^4} \quad (110 in^4)$$

(Cont)

PERKIN-ELMER

BOLLER & CHIVENS DIVISION

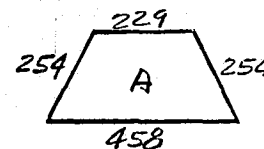
916 MERIDIAN AVENUE

SOUTH PASADENA, CALIFORNIA 91030

TELEPHONE: (213) 682-3391

DESIGN ANALYSISA/EPT FOR SUOTNASA / JSCJOB No. 5906FSHEET OF DATE 2-27-76BY O. ROURKEFORK TINES - PROPERTIES (CONT)TORSIONAL SHAPE FACTOR

look Case 9 p 195

 $K = \text{TORSIONAL SHAPE FACTOR}$ $U = \text{LENGTH OF MEDIAN BOUNDARY} = .458 + .254 + .229 + .254 = 1.195 \text{ m}$ $A = \text{AREA WITHIN MEDIAN BOUNDARY} = \frac{.458 + .229}{2} (.254) = .08725 \text{ m}^2$ $t = \text{WALL THICKNESS} = .006 \text{ m}$

$$K = \frac{4A^2t}{U} = \frac{4(.0873)^2(.006)}{1.195} = \frac{1.53 \times 10^{-4} \text{ m}^4}{(367 \text{ IN}^4)}$$

FLEXURAL TO TORSIONAL RIGIDITY RATIO

$$\lambda_y = \frac{EI_y}{GK} = 1.60$$

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SOUTH PASADENA, CALIFORNIA 91030

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DESIGN ANALYSISA/EPT FOR SUOTNASA / JSCJOB No. 5906PSHEET OF DATE 2-27-76BY O'RourkeLIST OF REFERENCES

- 1 PAYLOAD ACCOMODATION HANDBOOK - MAY 1975
ESA/ESTEC, NOORDWYK, THE NETHERLANDS
- 2 RAYMOND J. ROARK "FORMULAS FOR STRESS
AND STRAIN" FOURTH EDITION, MC GRAW-HILL
- 3 "PROGRESS REPORT ON SUOT FOR SHUTTLE"
BBRC, 3 MAY 1975 TO 1 JUNE 1975.
- 4 "FEASIBILITY STUDY OF THE SPACELAB ULTRAVIOLET
OPTICAL TELESCOPE FACILITY" FINAL REPORT,
BBRC, OCTOBER 1975.
- 5 ALEXANDER BLAKE "HOW TO FIND DEFLECTIONS AND
MOMENT OF RINGS AND ARCUATE BEAMS", AEROJET
GENERAL CORP, SACRAMENTO, CALIF.
- 6 W. R. PETRI, "EQUATIONS FOR 5 TAPERED CANTILEVER
BEAMS", DOMINION ALUMINUM FABRICATING LTD,
TORONTO, CANADA
- 7 "DEFLECTION CURVES FOR MOMENT BEARING No. 6684-1"
KEENE CORP, KAYDON BEARING DIVISION.

APPENDIX B

EFFECTS OF CREW MOTIONS AND VERNIER THRUSTERS ON TRACKING AND IMAGE STABILIZATION

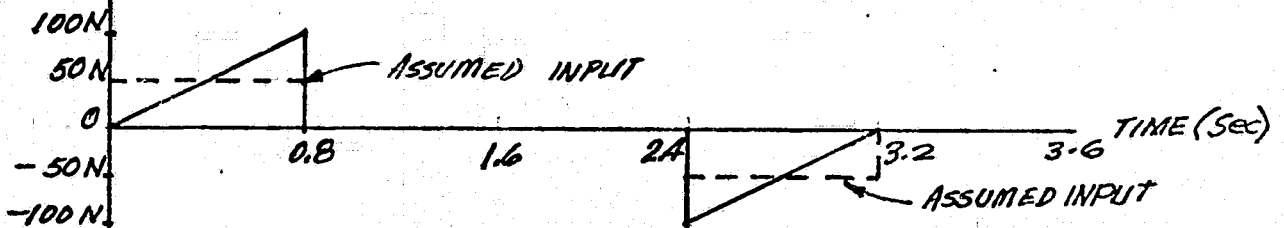
The following three pages show the effect of crew motion and small thruster firings on the tracking and image stabilization for the AFPT. The first curve plotted on each page shows the input disturbance. The second plot shows the resulting motion of the shuttle vehicle. The third plot shows the pointing error of the main telescope mount caused by the vehicle motion. The last plot shows the excursion of the image from its nominal position in focal plane. All the curves are based on a 0.1 second time constant and an effective overdamped condition for the servo system.

EFFECT OF CREW MOTION ON TRACKING AND IMAGE STABILIZATION

REPRODUCIBILITY OF THE
ORIGINAL PAGE IS POOR

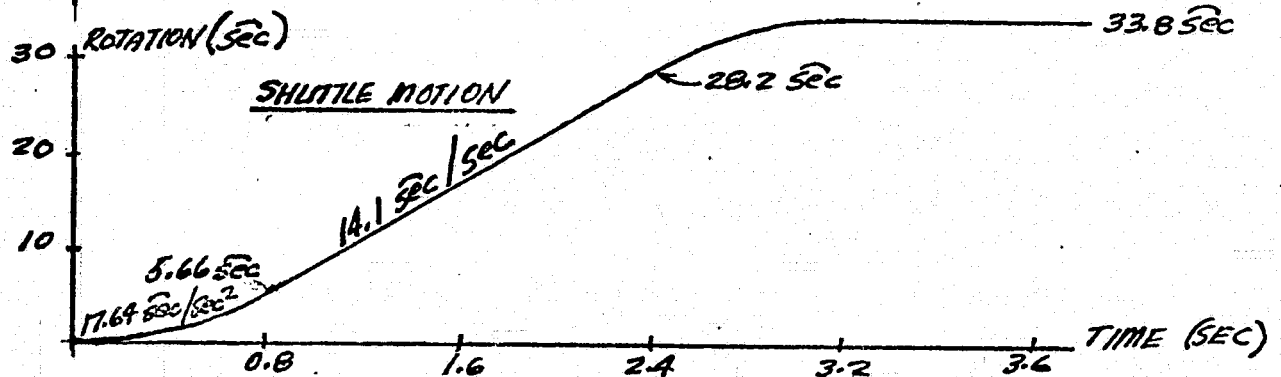
FORCE (N)

CREW INPUT



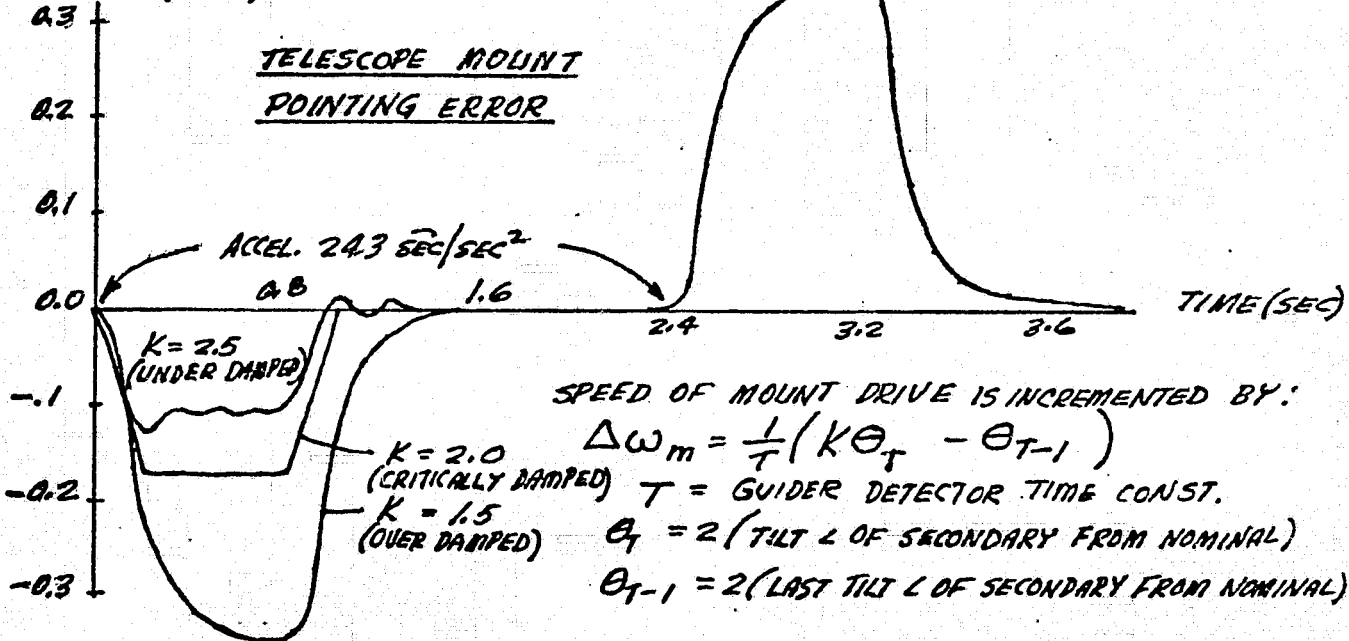
ROTATION (Sec)

SHUTTLE MOTION



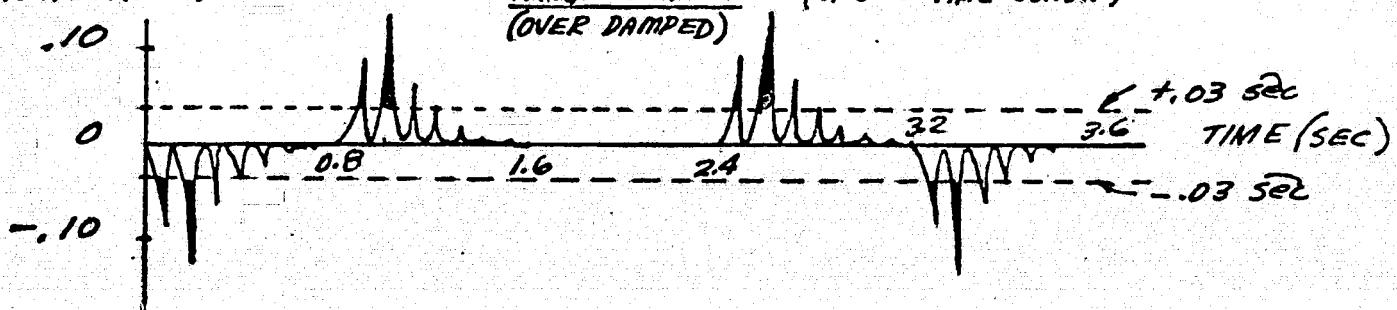
ERROR (Sec)

TELESCOPE MOUNT
POINTING ERROR

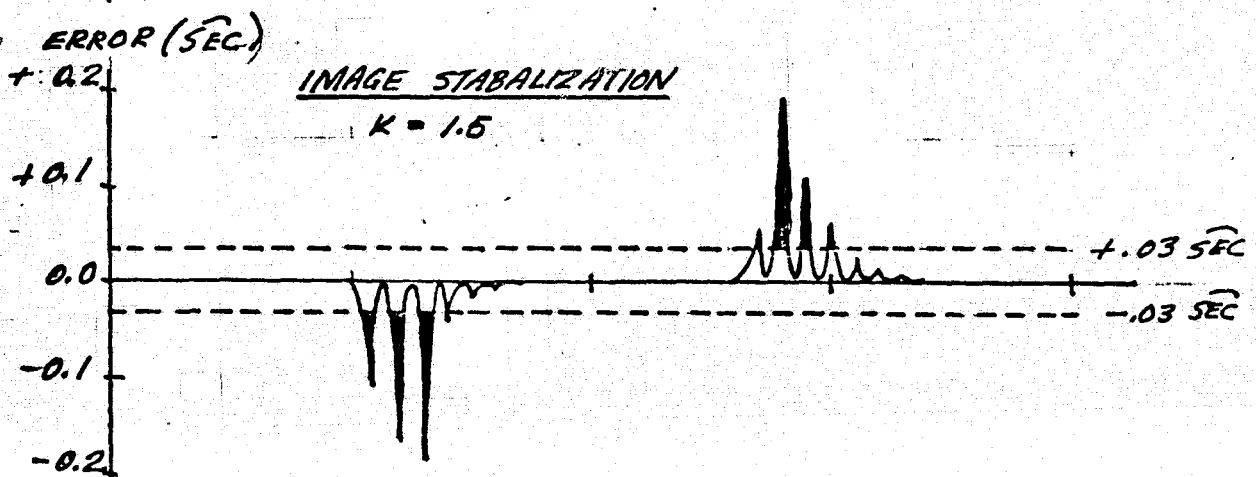
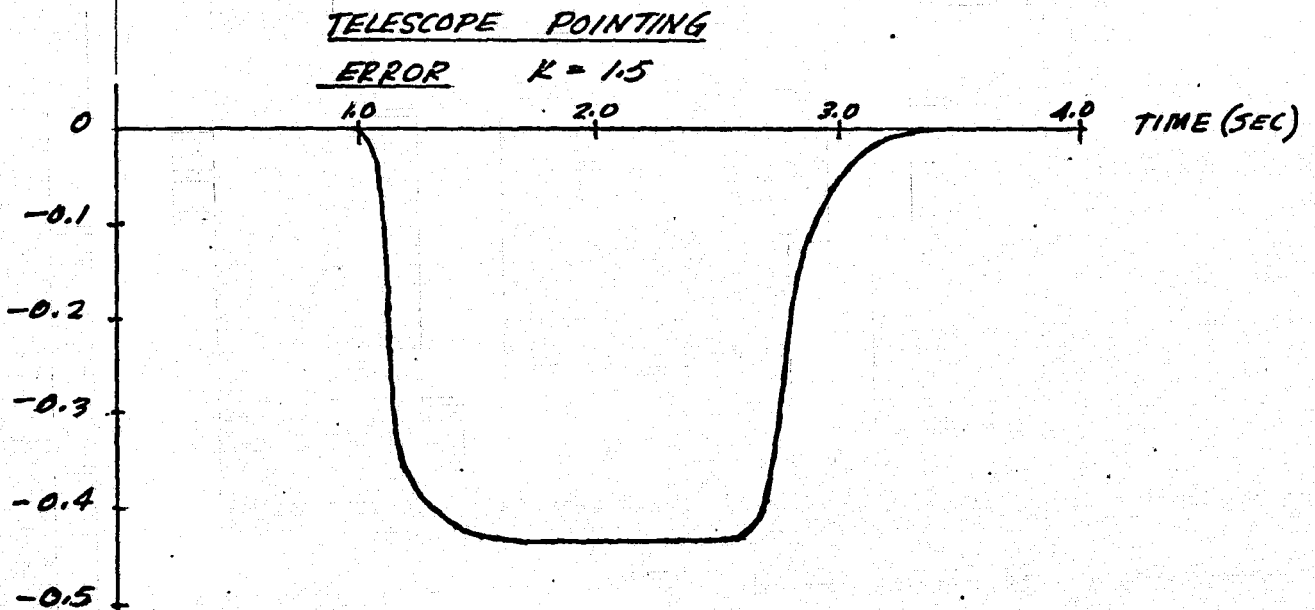
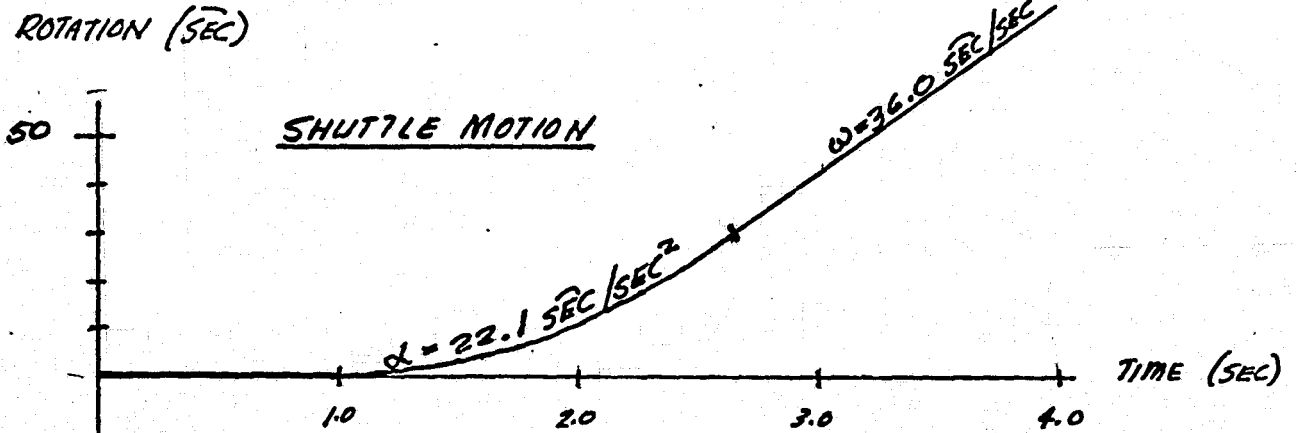
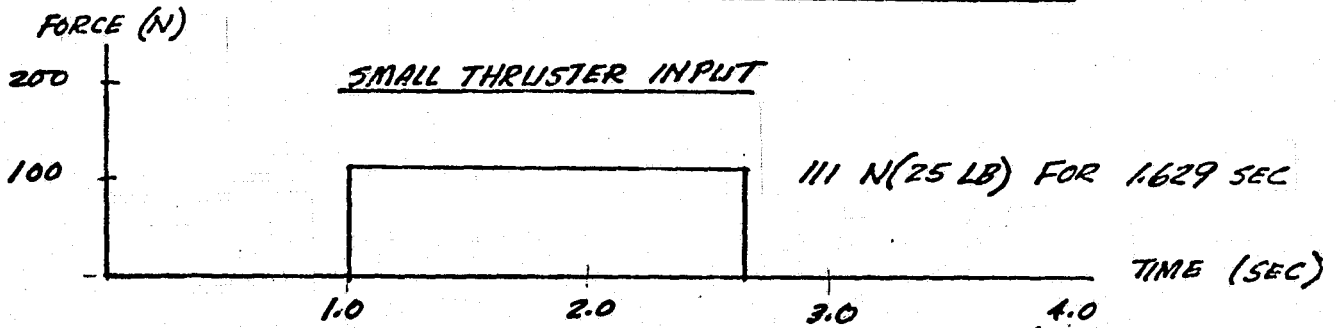


DISPLACEMENT (Sec)

IMAGE ERROR (.1 SEC TIME CONST.)
(OVER DAMPED)



EFFECT OF SMALL THRUSTER (LONG BURN) ON TRACKING AND IMAGE STABILIZATION



EFFECT OF SMALL THRUSTER (SHORT BURN) ON TRACKING AND IMAGE STABILIZATION

